Journal

WATER POLLUTION CONTROL FEDERATION

Special Features

Preaeration—Seidel and Baumann

Petrochemical Wastes—Gaudy et al.

Anaerobic Digestion—McCarty and McKinney

Fluorides and Fish—Angelovic et al.

Chlorine Determinations—Rand and Hunter

Volatile Acids—Di Lallo and Albertson

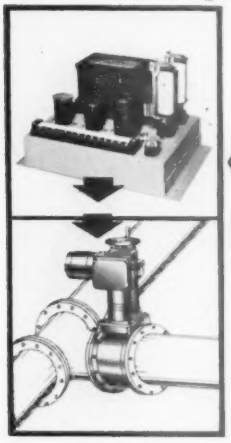
Operator's Manual

NEW MAILING SYSTEM—PAGE 444

APRIL 1961

BIF POSITIVE CONTROL OF MATERIALS FLOW

Remote pump and valve control...



with immediate report-back... all over two wires!

B-I-F Supervisory Control simplifies remote operations!

Receive positive, immediate report-back that you have started or stopped a pump miles away at a predetermined flow, level or pressure . . . that a distant valve (as illustrated) has started, stopped, or throttled a vital process flow . . . with B-I-F's simple, economical Synchro-Scan Position Indicator Controller.

These compact, low cost, reliable units are easy to install and operate . . . provide centralized control and continuous position indication of remotely located valves, gates, feeders and similar devices. System consists of two units, one at remote end and other at central dispatching center . . . and the single pair of conductors that connect them. Plug-in design assures quick accessibility, minimum maintenance, adaptability to cabinets or panels of many styles . . . dependable, accurate performance!

B-I-F Industries

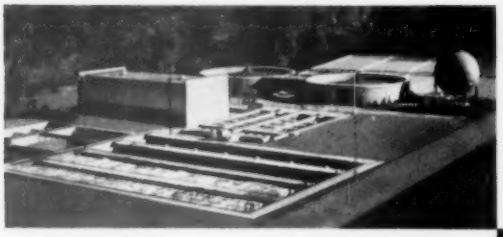
BUILDERS-PROVIDENCE • PROPORTIONEERS • OMEGA METERS • FEEDERS • CONTROLS / CONTINUOUS PROCESS ENGINEERING

Request Bulletin 240.20-3 for complete details. Write . . .
B-I-F Industries, Inc., 368 Harris Ave., Providence 1, R. I.

SAFER, MORE EFFECTIVE MUNICIPAL SEWAGE TREATMENT

"from Chicago"

Pleasant Hills Authority, Pennsylvania



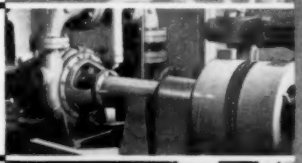
Exclusively Successful Sewage Treatment Equipment

Consoer, Townsend & Associates—Engineer

The Rust Engineering Company—Contractor

Swing Diffuser Air Diffusion Equipment for Dependable, Continuous Aeration.

SP-5 Pumps for High Head, Heavy Duty Raw Sewage Pumping



OTHER CHICAGO PUMP EQUIPMENT AT PLEASANT HILLS

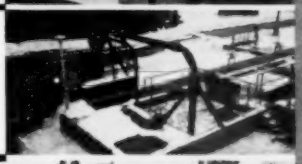
Chicago Comminutors

Non Clog Sewage Pumps

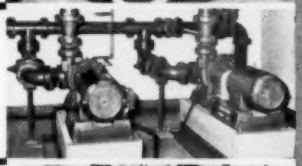
Utility Water Pumps

Precision Diffuser Tubes

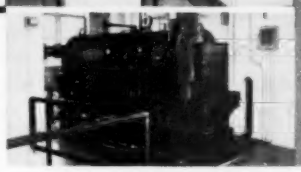
Aer-Degritter Grit Removal System for Controlled Washing, Transporting and Concentrating Grit



Scru-Peller Pumps for Clog-Proof Primary Sludge Pumping



Chicago-Cyclotherm Sludge Heat Exchanger and Digester Heater



Putting Ideas to Work

FOOD MACHINERY AND CHEMICAL CORPORATION

HYDRODYNAMICS DIVISION

CHICAGO PUMP

622 DIVERSEY PARKWAY • CHICAGO 14, ILLINOIS

See your Distributor for further information. Distributors located in principal Cities throughout the United States and Foreign Countries, or write Chicago Pump.

© 1961 CPC

JOURNAL of the WATER POLLUTION CONTROL FEDERATION

Volume 33 | April 1961 | Number 4

CONTENTS

• ARTICLES

Effect of Preaeration on the Primary Treatment of Sewage ..... Harris F. Seidel and E. Robert Baumann 339

Volatile Acids by Direct Titration ..... Rosemarie Di Lallo and Orris E. Albertson 356

Toxicity of Chromium Compounds Under Aerobic Conditions ..... Robert S. Ingols and Robert H. Fetner 366

Temperature and Fluorosis in Rainbow Trout ..... Joseph W. Angelovic, William F. Sigler, and John M. Neuhold 371

Stripping Kinetics of Volatile Components of Petrochemical Wastes .. A. F. Gaudy, Jr., R. S. Engelbrecht, and B. G. Turner 382

Comparison of Chlorine Determination Methods in Wastewaters ..... M. C. Rand and Joseph V. Hunter 393

Salt Toxicity in Anaerobic Digestion .... Perry L. McCarty and Ross E. McKinney 399

Arsenic Accumulation by Fish in Lakes Treated with Sodium Arsenite
William W. Ullmann, Robert W. Schaefer, and Wallace W. Sanderson 416

Operation of Sewage Treatment Plants

Chapter 16. Intermittent Sand Filters 419

Chapter 17. Disinfection and Chlorination 423

Chapter 18. Effects of Industrial Wastes on Sewage Treatment 432

• OTHER FEATURES

News and Notes 443

Mailing List Conversion (Editorial) 444

WPCF Member Associations 180a

Member Associations Meetings 182a

Water Pollution Control Product Guide 204a

Equipment and Supplies 205a

Proceedings of Member Associations

South Dakota Water Pollution Control Association 209a

Alabama Water and Sewage Association 211a

Swiss Association of Water and Sewage Professionals 213a

Index to Advertisers 226a

Ralph E. Fuhrman, *Editor*, 4435 Wisconsin Ave., Washington 16, D. C.

Robert A. Canham, *Associate Editor* Philip A. Ridgely, *Production Manager*

Mailing Permit: Second class postage paid at Lancaster, Pa., and at additional mailing offices.

On Guard

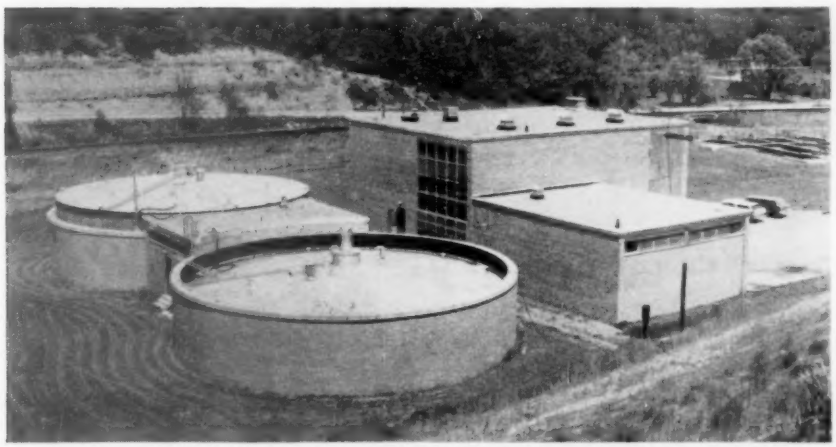
against pollution with P.F.T. equipment at Bethel, Pennsylvania

The Borough of Bethel, Pennsylvania has become the fifth largest borough in population in the entire state even though it is only 65% developed.

Rapidly expanding, 400 new homes being built each year and increasing numbers of new industries moving into this area, Bethel's civic leaders have recognized the need of an efficient sewage treatment plant.

Today, this modern sewage treatment plant is a major factor in attracting new industries and assuring the healthy growth and development of this area.

The following P.F.T. equipment is giving Bethel a plant providing an effective and important health-guard for this community. 1 P.F.T. 55′ Floating Cover, 1 P.F.T. 55′ Spiral Guided Gas Holder; both provided with a P.F.T. Gas Recirculation System, P.F.T. Insulated Aluminum Roofing, 2 P.F.T. Liquidometer Cover Position Indicators with High and Low Level Alarms, 1 P.F.T. #750 Heater and Heat Exchanger Unit and P.F.T. Gas Safety Equipment.



Bethel's Sewage Treatment Plant Designed by Chester Engineers, Consulting Engineers, Pittsburgh, Pa.

P.F.T. *waste treatment equipment exclusively since 1893*

PACIFIC FLUSH TANK CO.

4241 RAVENSWOOD AVENUE, CHICAGO 13, ILLINOIS

PORT CHESTER, N.Y. • SAN MATEO, CALIF. • CHARLOTTE, N.C. • JACKSONVILLE • DENVER

WATER POLLUTION CONTROL FEDERATION

PRESIDENT

RAY E. LAWRENCE
Black & Veatch
P. O. Box 8405
Kansas City 14, Missouri

VICE–PRESIDENT

HARRY E. SCHLENZ, President
Pacific Flush Tank Company
4241 Ravenswood Avenue
Chicago 13, Illinois

TREASURER

A. H. NILES, Consultant
433 N.E. 33rd Street
Boca Raton, Florida

EXECUTIVE SECRETARY–EDITOR

RALPH E. FUHRMAN
4435 Wisconsin Avenue
Washington 16, D. C.

DIRECTORS

Ex-Officio: MARK D. HOLLIS
Alabama: JOHN M. BOLTON (1963)
Alaska: LAMAR HUBBS (1963)
Arizona: E. O'NEAL DYE (1961)
Arkansas: M. L. WOOD (1961)
California: H. HARVEY HUNT (1961); R. D. BARGMAN (1962)
Canada: C. G. RUSSELL ARMSTRONG (1961)
Central States: E. J. BEATTY (1962); H. G. ROGERS (1963)
England (I.S.P.): W. F. A. SNOOK (1962)
England (I.P.H.E.): J. M. L. BOGLE (1962)
Federal: G. E. MCCALLUM (1962)
Florida: D. B. SMITH (1962)
Georgia: M. B. NIXON (1962)
Germany: WILHELM HUSMANN (1962)
Indiana: W. W. MATHEWS (1961)
Iowa: H. S. SMITH (1962)
Kansas: CARL F. HODGKINSON (1963)
Kentucky-Tennessee: M. A. CHURCHILL (1961)
Louisiana: H. J. SCIONEAUX (1961)
Maryland-Delaware: WILLIAM A. HASPURTHER (1963)
Michigan: GEORGE E. HUBBELL (1961); G. F. WYLLIE (1963)
Mississippi: G. M. LESTER (1963)
Missouri: WILLIAM G. RIDDLE (1963)
Montana: TOM SCHULTZ (1962)
Nebraska: T. A. FILIPI (1961)
New England: CHARLES G. HAMMANN (1963)
New Jersey: JOHN J. HORGAN (1963)
New York: G. A. FLEET (1962); R. C. SWEENEY (1963)
New Zealand: P. R. PARR (1962)
North Carolina: LEE S. DUKES, JR. (1961)
North Dakota: NORMAN PETERSON (1962)
Ohio: EARL F. WITTMER (1963)
Oklahoma: L. L. SETTLE (1962)
Pacific Northwest: R. T. SMITH (1962)
Pennsylvania: H. W. MCELHANEY (1961); S. I. ZACK (1963)
Puerto Rico: G. FLAQUE-GARCES (1962)
Rocky Mountain: ANTHONY ROSSI (1963)
South Carolina: J. D. LESSLIE (1961)
South Dakota: DON C. KALDA (1962)
Sweden: V. JANSA (1962)
Switzerland: ANDRÉ KROPF (1963)
Texas: J. L. ROBINSON (1963)
Utah: HOWARD HURST (1963)
Virginia: E. H. RUEHL (1962)
West Virginia: P. T. ARBUCKLE (1962)
At Large: CLAIR N. SAWYER (1961)
At Large: A. J. STEFFEN (1962)
At Large: ANDREW H. WAHL (1963)
At Large (WSWMA): W. A. DARBY (1962)
At Large (WSWMA): ALAN F. NAGLE (1963)
At Large (WSWMA): E. M. JONES (1963)

JOURNAL of the WATER POLLUTION CONTROL FEDERATION®

A monthly journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works. The Journal was known as *Sewage Works Journal* until January 1950; thereupon it became *Sewage and Industrial Wastes* until January 1960, when it assumed its present name.

EDITORIAL AND EXECUTIVE OFFICES: 4435 Wisconsin Ave., N.W., Washington 16, D. C. Send all manuscripts, advertising copy, subscriptions, address changes, etc., to this address. JOURNAL WPCF is published monthly by the Water Pollution Control Federation at Prince & Lemon Sts., Lancaster, Pa.

SUBSCRIPTION RATES: Members of local associations affiliated with the Federation, $8.00 per calendar year. All others, U. S. and Canada: $10.00; other countries, $11.50. (Foreign subscriptions must be accompanied by International Money Order.) Single copies: United States: $1.25 each; foreign, $1.50 each.

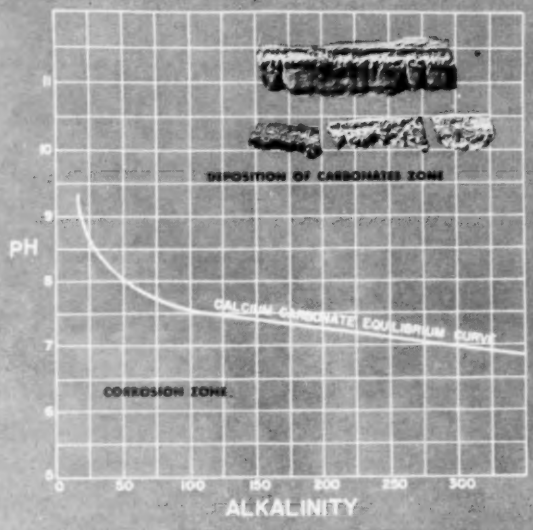
CLAIMS: No claims will be allowed for copies of Journals lost in the mails unless such claims are received within sixty (60) days of the date of issue and no claims will be allowed for issues lost as a result of insufficient notice of change of address. "Missing from files" cannot be accepted as the reason for honoring a claim.

REFERENCE SERVICE: JOURNAL of the WATER POLLUTION CONTROL FEDERATION is indexed regularly by *Industrial Arts Index* and *Engineering Index*. Microfilm copies of this JOURNAL may be procured from University Microfilms, Ann Arbor, Mich. This service is limited to regular subscribers only.

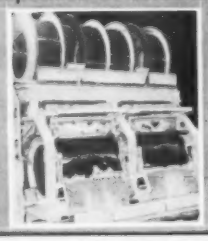
Library of Congress Catalog Card Number: 42–19992.

Copyright © 1961, by the Water Pollution Control Federation. Reprints from this publication may be made only if permission of the Editor is secured and on condition that the full title of the article, name of the author and complete reference are given. The Federation assumes no responsibility for opinions or statements of facts expressed in papers or discussions published in this JOURNAL.

"ROTO-PLUG" SLUDGE CONCENTRATOR
ELIMINATES COSTLY FILTER MEDIA MAINTENANCE



The *Roto-Plug® Sludge Concentrator dewaters sewage sludge without the use of conditioning chemicals. This feature eliminates the costly problem of periodic acid washing of filter media to remove calcium carbonate deposits. Where chemicals are used to condition sludge it adjusts the pH of the sludge upward to pH 9 or higher and causes the formation of calcium carbonate. When referred to the carbonate equilibrium curve of water practice, the condition of the sludge is found to be high in the "deposition of carbonate zone".



The *Roto-Plug® works with the sludge "as is" thereby eliminating the age-old problem of decreased production due to calcium carbonate blinding of filter media.

For full details about the economical *Roto-Plug® method of dewatering sewage sludge write for our four-page illustrated folder RP-100.

NICHOLS Engineering & Research Corp.
80 Pine Street, New York 5, New York

3513 N. Hovey Street, Indianapolis 18, Ind. • 1336 North Carolan Ave., Burlingame, Calif.

*Equipment Development Corp.

WPCF MEMBER ASSOCIATIONS

Alabama Water and Sewage Assn.*
E. J. FINNELL, JR., *Act.-Sec.*, Univ. of Alabama, University, Ala.

Alaska Water Management Assn.
CHARLES F. WALTERS, *Sec.-Treas.*, Arctic Health Research Center, P. O. Box 960, Anchorage, Alaska

Arizona Sewage and Water Works Assn.*
A. D. COX, *Sec.-Treas.*, 2612 N. 16th St., Phoenix, Ariz.

Arkansas Water and Sewage Conf.*
DR. C. W. OXFORD, *Sec.-Treas.*, College of Engineering, University of Arkansas, Fayetteville, Ark.

California Sewage and Industrial Wastes Assn.
ROBERT L. WHITE, *Sec.-Treas.*, Bureau of Engr., City Hall, Burbank, Calif.

Canadian Institute on Sewage and Sanitation
DR. A. E. BERRY, *Sec.-Treas.*, Administrative Office, 72 Grenville St., Toronto, Ont., Canada

Central States Sewage and Industrial Wastes Assn.
SCOTT E. LINSLEY, *Sec.-Treas.*, 2400 Childs Rd., St. Paul 6, Minn.

(England) Institute of Sewage Purification
W. F. A. SNOOK, *Sec.*, 10, Cromwell Pl., South Kensington, London, S. W. 7, England

(England) Institution of Public Health Engineers
ERNEST V. BALSOM, *Sec.*, 179 Vauxhall Bridge Rd., London, S. W. 1, England

Federal Sewage Research Assn.
MARTIN F. KUNKEL, *Sec.-Treas.*, Rm. 4232, HEW South Bldg., Washington 25, D. C.

Florida Pollution Control Assn.
VINCENT D. PATTON, *Sec.-Treas.*, State Board of Health, Box 210, Jacksonville 1, Fla.

Georgia Water and Sewage Assn.*
ROBERT S. INGOLS, *Sec.-Treas.*, Prof. of Applied Biology, Georgia Institute of Tech., Atlanta, Ga.

(Germany) Abwassertechnische Vereinigung
KARL REGER, *Sec.-Treas.*, 8 Bertha-von-Suttner-Platz, Bonn, Germany

Indiana Water Pollution Control Assn.
VICTOR G. WAGNER, *Sec.-Treas.*, State Dept. of Health, 1330 W. Michigan St., Indianapolis 7, Ind.

Iowa Water Pollution Control Assn.
L. F. SKORCZESKI, *Sec.*, 207 S. 15th Ave., Marshalltown, Iowa

Kansas Water Pollution Control Assn.
HOWARD F. SAIGER, *Sec.-Treas.*, 1900 E. Ninth, Wichita, Kans.

Kentucky-Tennessee Water Pollution Control Assn.
S. LEARY JONES, *Sec.-Treas.*, 602 Cordell Hull Bldg., Nashville 3, Tenn.

Louisiana Conference on Water Supply and Sewerage*
GEORGE H. WEST, *Sec.-Treas.*, P. O. Box 895, Water Dept., Lake Charles, La.

Maryland-Delaware Water and Sewage Assn.*
W. M. BINGLEY, *Sec.-Treas.*, State Dept. of Health, 301 W. Preston St., Baltimore 1, Md.

Michigan Sewage and Industrial Wastes Assn.
D. M. PIERCE, *Sec.-Treas.*, Michigan Dept. of Health, Rm. 331, Admin. Bldg., Lansing 4, Mich.

Mississippi Sewage and Industrial Wastes Assn.
NEIL G. MCMAHON, *Sec.-Treas.*, Mississippi State Board of Health, Jackson, Miss.

Missouri Water Pollution Control Assn.
JACK K. SMITH, *Sec.-Treas.*, Water Pollution Control Bd., 112 W. High, P.O. Box 154, Jefferson City, Mo.

* Water Pollution Control Section.

Montana Sewage and Industrial Wastes Assn.
A. W. CLARKSON, *Sec.-Treas.*, Div. of Environ. Sanit., State Board of Health, Helena, Mont.

Nebraska Sewage and Industrial Wastes Assn.
E. BRUCE MEIER, *Sec.-Treas.*, Kirkham, Michael & Assoc., 508 S. 19th St., Omaha 2, Nebr.

New England Water Pollution Control Assn.
RICHARD F. GREELEY, *Sec.-Treas.*, Massachusetts Dept. of Pub. Health, 511 State House, Boston 33, Mass.

New Jersey Water Pollution Control Assn.
ANTHONY T. LEAHEY, *Sec.-Treas.*, P. O. Box 32, West Trenton, N. J.

New York Water Pollution Control Assn.
RALPH C. SWEENEY, *Sec.*, State Dept. of Health, 55 Church St., White Plains, N. Y.

New Zealand Sewage and Industrial Wastes Assn.
K. R. DAVIS, *Hon. Sec.-Treas.*, Auckland Metrop. Drain. Bd., P. O. Box 208, Auckland C. 1, New Zealand

North Carolina Water Pollution Control Assn.
T. Z. OSBORNE, *Sec.-Treas.*, Rm. 309 Municipal Bldg., Greensboro, N. C.

North Dakota Water Pollution Control Assn.
W. VAN HEUVELEN, *Sec.-Treas.*, State Dept. of Health, Bismarck, N. Dak.

Ohio Water Pollution Control Conf.
E. B. RANSOM, *Sec.-Treas.*, Div. of San. Engr., Dept. of Health, 101 N. High St., Columbus 15, Ohio

Oklahoma Water, Sewage and Industrial Wastes Conf.*
H. M. CRANE, *Sec.-Treas.*, 3400 Northeastern, Oklahoma City 5, Okla.

Pacific Northwest Pollution Control Assn.
GILBERT H. DUNSTAN, *Sec.-Treas.*, P. O. Box 176, Pullman, Wash.

Pennsylvania Water Pollution Control Assn.
J. R. HARVEY, *Sec.-Treas.*, Pennsylvania Dept. of Health, 996 S. Main St., Meadville, Pa.

Puerto Rico Water and Sewage Works Assn.
ROBERT J. AULD, *Sec.-Treas.*, Espana 2015, Ocean Park, Santurce, P. R.

Rocky Mountain Sewage and Industrial Wastes Assn.
JOHN W. HERNANDEZ, *Sec.-Treas.*, 408 Galisteo St., Santa Fe, N. Mex.

South Carolina Water and Sewage Works Assn.*
ROBERT N. BOWEN, *Sec.-Treas.*, 417 Wade Hampton Bldg., Columbia, S. C.

South Dakota Water Pollution Control Assn.
DON C. KALDA, *Sec.-Treas.*, Div. of San. Engr., State Board of Health, Pierre, S. Dak.

(Sweden) Föreningen för Vattenhygien
ERIK JONSSON, *Sec.*, Box 5038, Stockholm 5, Sweden

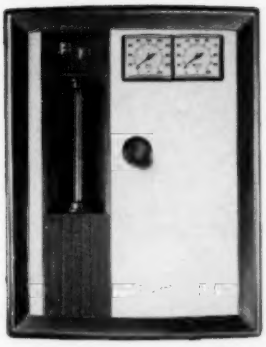
(Switzerland) Verband Schweizerischer Abwasserfachleute
PIERRE WILDI, *Sec.*, Hegemmatt 28, Zurich 2/38, Switzerland

Texas Water and Sewage Works Assn.*
G. R. HERZIK, JR., *Sec.-Treas.*, Div. of San. Engr., State Dept. of Health, Austin, Tex.

Utah Water Pollution Control Assn.
WILLIAM W. ANDERTON, *Sec.-Treas.*, 2500 S. State St., Salt Lake City 15, Utah

Virginia Industrial Wastes and Sewage Works Assn.
ORVAL J. HAND, *Sec.-Treas.*, Hercules Powder Co., Hopewell, Va.

West Virginia Water Pollution Control Assn.
GLEN O. FORTNEY, *Sec.-Treas.*, State Dept. of Health, Charleston 5, W. Va.



This, believe it or not, is a wall mounted chlorinator. Its attractive appearance is our way of showing how proud we are of the advanced operating parts hidden behind the front panel. For example: This is the first wall mounted chlorinator ever to feature a single stack regulator. Simple, compact appearance belies the fact that it can handle up to 200 pounds per day of chlorine more accurately, dependably, and safely than any other chlorinator with the single exception of its big brothers. It is so completely corrosion-proof in the right places that we have little hope of ever selling replacement units. In short, we have never been happier with any product than we are with the new Series 3600 chlorinators .

Should you wish to order one of these beauties sight-unseen, on our say-so, we can deliver immediately from warehouse stocks across the country. If not, your local F&P field office will gladly demonstrate the 3600 Series at your plant, at your convenience. Call for an appointment. Or, write for complete information in Bulletin 70C3600. Fischer & Porter Company, 1141 Fischer Road, Warminster, Pa.

FP

FISCHER & PORTER COMPANY

INSTRUMENTATION AND CHLORINATION

These MANUFACTURING AFFILIATES carry Fischer & Porter engineering designs to the far corners of the earth: FISCHER & PORTER (CANADA) LTD., DOWNSVIEW, ONTARIO • FISCHER & PORTER LTD., WORKINGTON, CUMBERLAND, ENGLAND • FISCHER & PORTER G.m.b.H., GROSSELLERSHAUSEN, BEI GOTTINGEN, GERMANY • FISCHER & PORTER N.V., KOMEETWEG 11, THE HAGUE, NETHERLANDS • FISCHER & PORTER Pty LTD., 184 HANNA ST., SOUTH MELBOURNE, VICTORIA, AUSTRALIA.

MEMBER ASSOCIATIONS MEETINGS

Association *	*Date*	*Place*
Arizona	Apr. 20–22	Hotel Superstition Ho, Apache Junction (Location change)
California	Apr. 26–29	Hotel Miramar, Santa Monica
Virginia	May 8–9	Hotel Chamberlain, Old Point Comfort
Maryland-Delaware	May 22–24	Commander Hotel, Ocean City, Md.
Michigan	May 31–June 2	Michigan State University, East Lansing
Alabama	June 5–7	University of Alabama, Tuscaloosa
New England	June 7–8	Snow Inn, Harwichport, Mass.
Central States	June 7–9	Leland Hotel, Springfield, Ill.
Iowa	June 7–9	The New Inn, Okoboji
Ohio	June 14–16	Statler Hotel, Cleveland
ISP (England)	June 19–23	Brighton, England
Pennsylvania	Aug. 9–11	Pennsylvania State University, State College
Kentucky-Tennessee	Sept. 11–13	Brown Hotel, Louisville, Ky.
Germany	Sept. 12–16	Hamburg, Germany
South Dakota	Sept. 20–22	Sheraton Hotel, Rapid City
Missouri	Oct. 1–3	Kentwood Arms Hotel, Springfield

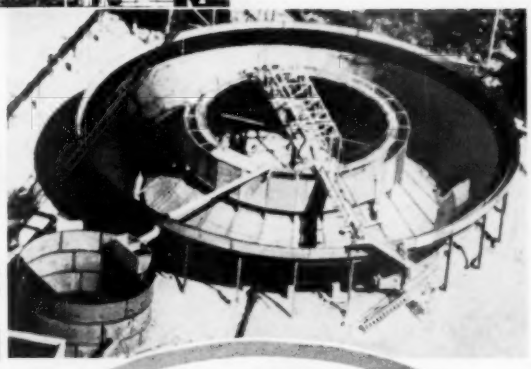
* See preceding left-hand page for full name.

THIRTY-FOURTH ANNUAL MEETING

Water Pollution Control Federation

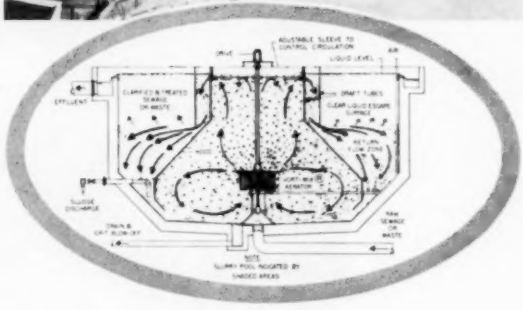
Host—Central States Sewage and Industrial Wastes Association
Milwaukee, Wisconsin

Technical Meetings and Exhibits—Auditorium
Hotel Headquarters—Schroeder
October 8–12, 1961



AERO-ACCELATOR®

Activated Sludge Plant for Sewage and Industrial Waste Treatment...



– 90% AND HIGHER B.O.D. REMOVALS!

– SPACE SAVINGS UP TO 50%!

– LOWEST INSTALLED COST!

The "AERO-ACCELATOR" plant offers a practical solution for complete treatment of organic industrial waste waters.

Using the most modern biological and hydraulic principles, "AERO-ACCELATOR" completely-mixed activated sludge plants carry on clarification together with biological oxidation of organic materials. They offer the additional advantages of efficient operation at high loadings, and stability under shock loads.

Bulletin 6510 will be sent on request.

Inquiries are invited on all water and waste treatment problems of municipalities, institutions and general industry.

INFILCO

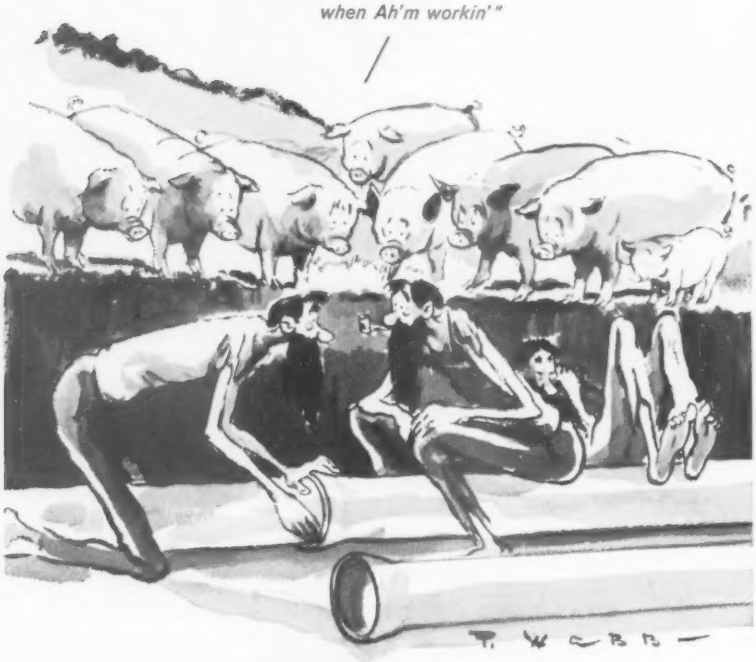
INFILCO Inc.
General Offices: Tucson, Arizona
Field offices throughout the United States and in other countries

Subsidiary of General American Transportation Corporation

GENERAL AMERICAN

THE ONLY COMPANY impartially offering equipment for ALL types of water and waste processing—coagulation, precipitation, sedimentation, filtration, ion exchange, flotation, and biological treatment. 517A

"Good thing this is simple...
Ah hates bein' watched
when Ah'm workin'"



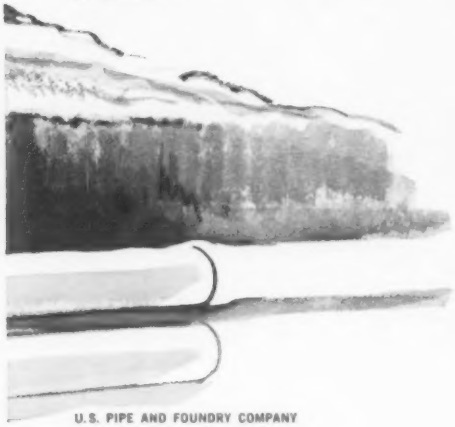
U.S. cast iron PIPE FOR WATER, SEWERAGE AND

worth looking into!

Fact! Whenever . . . wherever Tyton Joint* pipe goes into the ground it wins more than its share of attention.

And why not? Tyton's so simple . . . so easy to assemble . . . it's a joy to watch. Only one accessory needed—a rubber gasket. No bell holes. No nuts, bolts or caulking equipment. Reduces weather worries too . . . Tyton can be laid in rain or wet trench.

Simple, speedy, sure, Tyton Joint* pipe is one big answer to today's problem of steadily rising costs. Get the money, time and labor-saving facts today. Call or write.



U.S. PIPE AND FOUNDRY COMPANY
General Office: Birmingham 2, Alabama

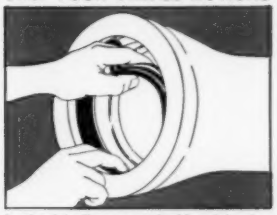
A Wholly Integrated Producer from Mines and Blast Furnaces to Finished Pipe.

* U.S. Patent No. 2,953,399

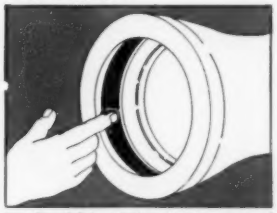
INDUSTRIAL SERVICE CAST IRON

TYTON®

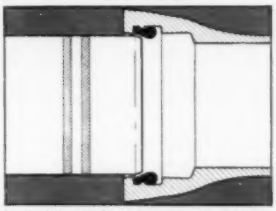
ONLY FOUR SIMPLE ACTIONS



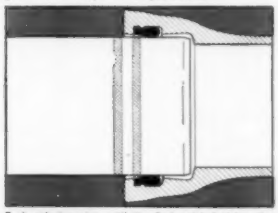
Insert gasket with groove over bead in gasket seat . . . a simple hand operation.



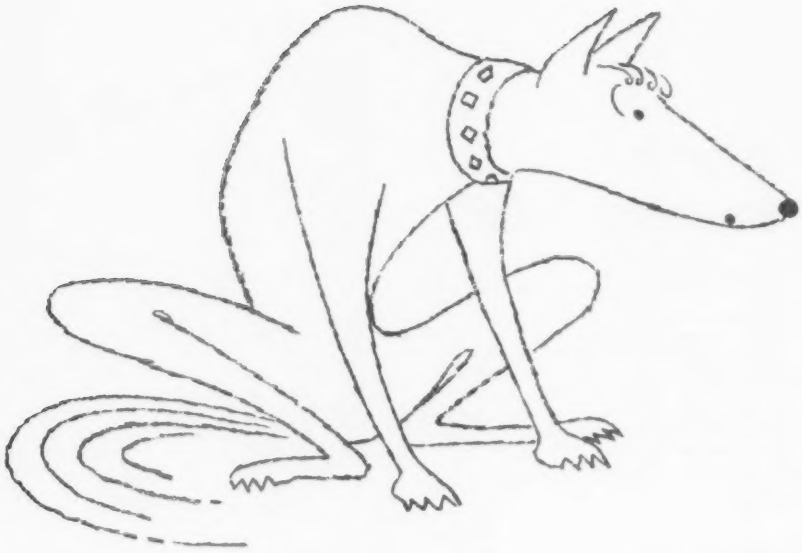
Wipe film of Tyton Joint* lubricant over inside of gasket. Your receiving pipe is ready.



Insert plain end of entering pipe until it touches gasket. Note two painted stripes on end.



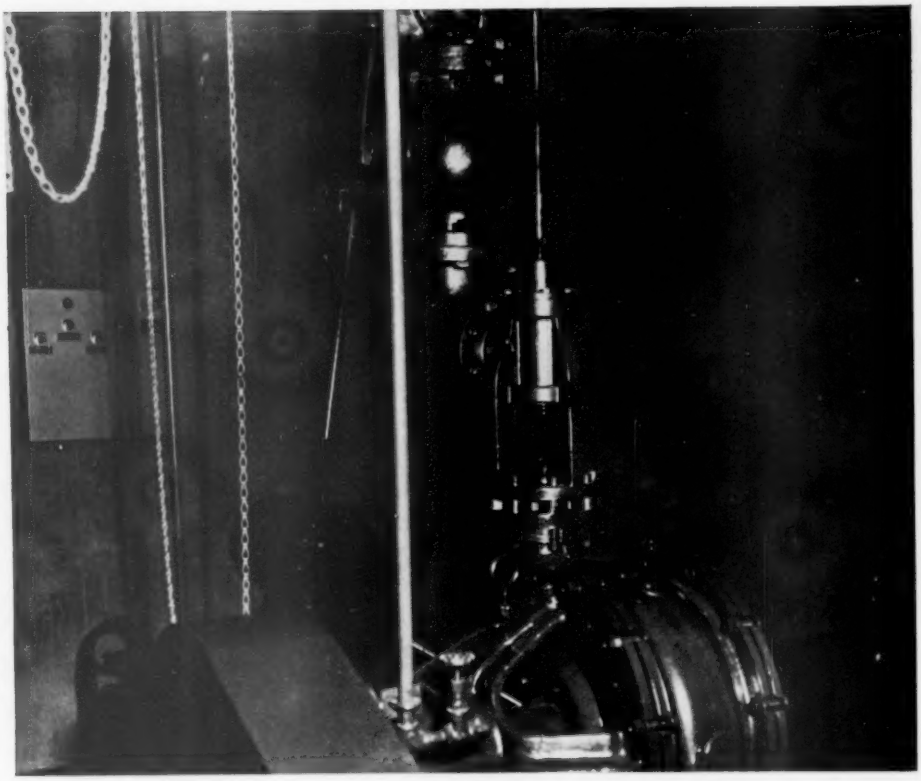
Push entering pipe until the first painted stripe disappears and the second stripe is approximately flush with bell face. The joint is sealed . . . bottle-tight, permanently! The job's done . . . . fast, efficiently, economically. Could anything be simpler?



No dog, this seeing eye!

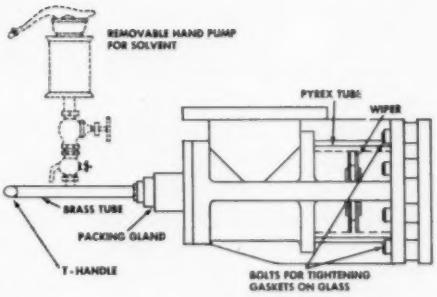
What started out as a favor to a friend (development of a Cleanable Sight Glass) has turned into one of our most gratifying enterprises. While not unusually profitable as a commercial venture, the good will implications are immense: over 500 sewage, water and industrial waste treatment plant operators throughout the world feel kindly toward Eimco-Process equipment because they can now *visually* control sludge withdrawal.

Think of it. Instead of guessing at that critical point where the heavy layer ends, they can see it. Instead of flying blind, they can witness the phenomenon of thin sludge being pulled through the heavy layer and, of course, take prompt remedial action (like shutting off the pump). And if grease in the sludge clouds the inside of the Pyrex, a little solvent injected through the hollow wiper rod and a few deft swipes of the wiper clear matters instantly.



Our obligation is clear: to make this inexpensive adjunct to efficient plant operation available to all operators as quickly as Eimco production schedules permit.

Your part is simple: if you have a 4″ or 6″ standard elbow in your sludge line, wire your Cleanable Sight Glass order and stand by with wrenches. Or, if you want to contemplate more facts and figures, send for Bulletin SM-1002. Either way, may we hear from you?

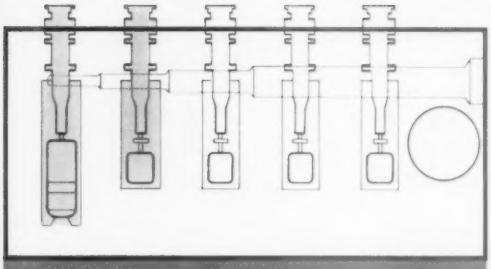


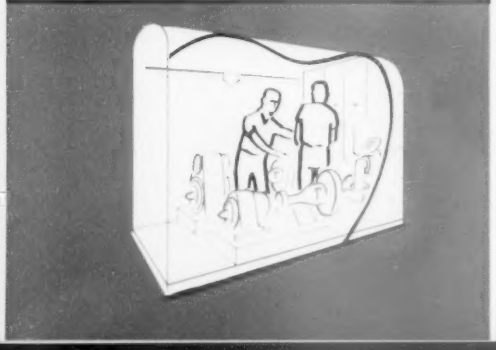
THE EIMCO CORPORATION

B-751

Process Engineers Division
420 Peninsular Avenue
San Mateo, California

TEX PACKAGED QUAD PUMP STATION ...shaped for GROWTH!





The new, *rectangular shape* of the TEX-QUAD Packaged Pump Station is designed to meet the needs of a growing community. It permits a larger sewage pumping station to be installed with only TWO pumps *initially*. Then, as the area to be served increases, additional pumps can be quickly, easily and inexpensively installed to handle the increased load. There's ample space in the TEX-QUAD for as many as *five pumps*, providing added capacities up to *10,000 GPM!*

Operators find normal servicing and maintenance of the TEX-QUAD sewage pump stations easier, too. The unique, *rectangular* design creates a *more spacious interior*. This is one of the important reasons why TEX-VIT stations are today's *"best buy"* for any community.

TEX-VIT
MANUFACTURING COMPANY
Formerly TEX-VIT Supply Company
P. O. BOX 117-J MINERAL WELLS, TEXAS

Write today for the new **TEX-QUAD CATALOG No. TQ-61.** It gives complete information on this new, rectangular **Packaged Pump Station.**

"Flexible" CAM DRIVE UNIRODER

An entirely new principle providing Non-Slip Rod Drive!

NO ROLLERS TO SCORE OR BURN

ANOTHER *"Flexible"* FIRST!

PAT. PENDING

UniRodeR Model SUR-1 rods sewers and is ideal for threading cable for bucket machines

CAMS GRIP TIGHTER UNDER LOAD

Revolutionary! Traveling cams push or pull the continuous rod, rotating with it in either direction. The heavier the load the tighter the cams grip the rod. NO FRICTION ROLLERS TO SCORE OR BURN. Exclusive Safety Overload Clutch protects pipe, machine and rod. Simplified mechanism and fewer working parts mean less maintenance than any other continuous rodder!

- 8 Speeds Forward or Reverse
- Positive Non-Slip Cam Drive
- Capacity up to 2000 ft.
- Tool Box, 3 cu. ft. Capacity
- All Moving Parts Enclosed
- Safety Overload Clutch
- Footage Meter
- Uses From ¼ to ⅜-in. Rod
- 9 hp. with Self Starter

FLEXIBLE INC.

415 S. Zangs Blvd., Dallas, Texas
Factories: Los Angeles, Calif. and Lima, Ohio

DON'T BE FOOLED BY INITIAL PIPE COSTS...

Certain factors concerning the type of pipe to be used for a proposed water or gas project must be examined carefully:

First—how much does the pipe cost, compared to other types?

Second—how often will it require repair?

Third—how long before it has to be replaced?

Sometimes the first cost of jobs where cast iron pipe is specified, is higher than similar projects using cheaper pipe. Yet, in the long run, cast iron pipe costs *less!* Here's why:

- Cast iron pipe rarely requires repairs. Its rugged construction, corrosion-resistant qualities and bottle-tight rubber-ring joints will withstand the most severe pressures.
- Cast iron pipe is built to *last*—98 American cities will testify to that. They've had cast iron pipe installations in constant use for over a century! Once cast iron pipe is in the ground, it stays there!

Don't be fooled by "low-cost" pipe. Insist on the pipe that will actually save you money over a period of years.

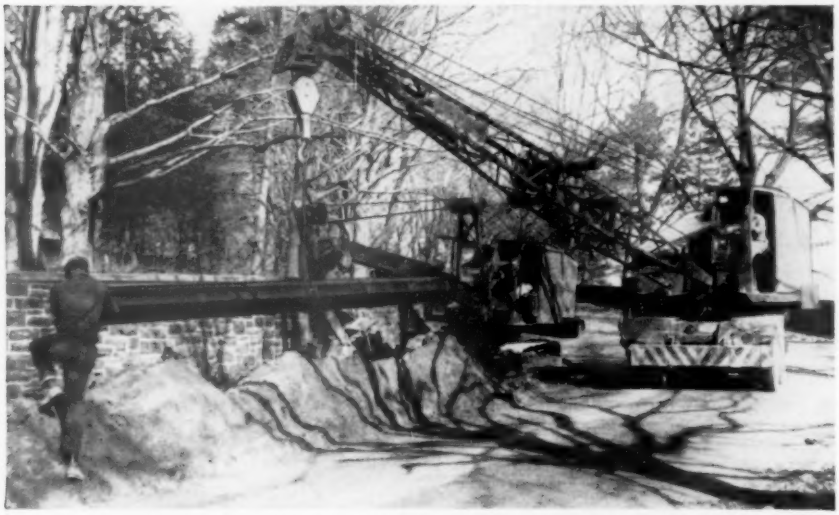
In Nebraska—Here a section of cast iron pipe is being relocated. Twenty-five years old, the pipe is still in excellent condition—has never required major repair . . . or replacement.

Rely on CAST IRON PIPE

In Indiana (above)—"All-weather" cast iron pipe is quickly installed despite wet trench conditions. Slip-on joints were easily assembled, with one workman using a crowbar.

In Kansas (above)—36" cast iron water main. Another part of this main was floated out of its trench by a heavy downpour. Later a 150 psi water test revealed no leaks in the slip-on joints!

In Pennsylvania (below)—This 16" cast iron pipe is being installed as fast as the trench hoe can prepare the trench. Handy lengths and slip-on joints make cast iron pipe easy to handle, even in crowded neighborhood sectors; require less labor.



CAST IRON PIPE
THE MARK OF THE 100-YEAR PIPE
Cast Iron Pipe Research Association, Thos. F. Wolfe
Managing Director, 3440 Prudential Plaza, Chicago 1, Ill.

ATLANTA, GA.
CHILLICOTHE, O.
CLEVELAND, O.
DENVER, COLO.
DETROIT, MICH.
E. ST. LOUIS, ILL.
HOPEWELL, VA.
JACKSONVILLE, FLA.
JOHNSONBURG, PA.
KALAMAZOO, MICH.
KENNEWICK, WASH.
MACON, GA.
MARCUS HOOK, PA.
MENASHA, WIS.
MIDDLETOWN, O.
MONROE, LA.
NEW ORLEANS, LA.
PINE BLUFF, ARK.
PORT ST. JOE, FLA.
SAN FRANCISCO
(PORT CHICAGO), CALIF.
SAVANNAH, GA.
TACOMA, WASH.
VANCOUVER, WASH.
WISCONSIN RAPIDS, WIS.
... and soon
EL SEGUNDO, CALIF.

When it comes to

ALUM

liquid or dry

Come to

GENERAL CHEMICAL

As one of America's primary producers of aluminum sulfate, General Chemical has established a network of strategically located plants from coast to coast. Those listed above can provide you with a close, convenient source of supply. These modern plants are located in the heart of active consuming areas. They facilitate service to you. They save transportation costs. In addition, our chain of warehouses across the country makes stocks of dry aluminum sulfate readily available everywhere. Write or phone today for further information on how these facilities can be put to work for you.

Basic to America's Progress

Allied Chemical

GENERAL CHEMICAL DIVISION
40 Rector Street, New York 6, N.Y.

Needham, Mass., Installs FIRST Plastic Sewer Main in U.S.A.

"Evanite stops INFILTRATION and EXFILTRATION, has a root-proof joint," says Sewer Superintendent

E. A. Symonds, Needham Superintendent of Sewers, selected Evanite Plastic Sewer Main in 8-inch diameters, plus plastic fittings and 4-inch plastic house connections, after extensive tests established Evanite as impervious to attack by chemicals found in sewage and industrial wastes. It was also determined that Evanite's non-absorptive quality, as compared with existing sewer pipe materials, eliminates percolation through the walls, and has adequate crushing strength for sewer main service under city streets.

Ease of installation also was a factor . . . Evanite can be cut with a saw and rejoined without further machining or working.

Evanite Plastic Pipe is guaranteed for 50 years

Evanite PLASTIC COMPANY

Evanite is the only producer of large diameter plastic sewer mains.

DIVISION OF THE EVANS PIPE COMPANY

LEESBURG, FLORIDA TELEPHONE: ST 7-1321 CARROLLTON, OHIO TELEPHONE: 68

One of the nation's largest producers of face brick, clay pipe, clay flue lining, wall coping, and related construction materials . . . with over 50 years of faster, friendlier service.

DO IT RIGHT WITH EVANITE *SEWER, GAS, WATER, IRRIGATION* PIPE EVA 160-119B

PARSHALL FLUME LINERS

PREFABRICATED TO SPEED CONSTRUCTION

● Ready for field installation! Parshall Flume Liners are prefabricated from "Chemstone E," an asbestos cement material impregnated with a special asphaltic compound under tremendous pressure. It will withstand shock, vibration and is impervious to most acids, alkaline solutions and rapid temperature changes. More durable than a concrete channel. Although strong enough to stand alone, it is generally used as a liner in concrete channels and serves as the inside form during the pour.

Tolerances are held within plus or minus 1/16"—well within the limits of accuracy for this type of metering.

Flume liners with throats 3" to 12" are furnished on skids completely assembled for quick, easy installation. For throats 18" to 96" the liners are furnished in two sections.

Write For FREE Literature and Specifications

FILTRATION EQUIPMENT CORPORATION
275 HOLLENBECK STREET, ROCHESTER 21, N. Y.

EXTENSIVE TESTS ESTABLISH VALUES for MANNING's *n*

There has been considerable loose talk lately about "new" values for Manning's *n* when figuring flow coefficients for sewer lines. Manufacturers of one substitute material for lifetime Vitrified Clay Pipe say their pipe has a lower *n* factor, allowing flatter grades or smaller diameter pipe.

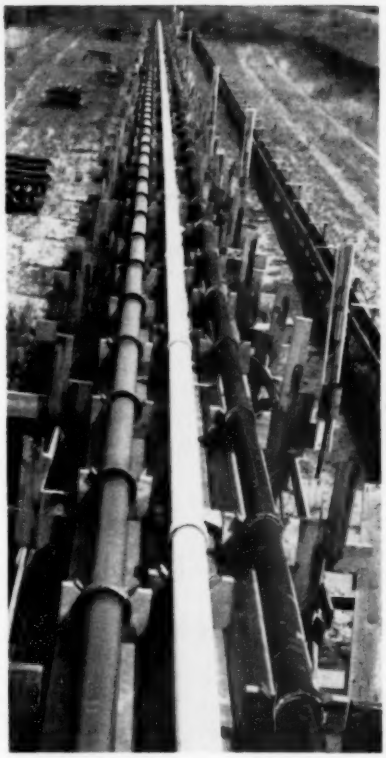
Independent tests show that this is not true.

For example, the new "Design and Construction of Sanitary and Storm Sewers"* manual contains a table entitled "Suggested Values of *n* for Manning's Formula." According to this table in the *new standard* for sanitary engineers, the range of values for *n* is *exactly the same* for lifetime Vitrified Clay Pipe and all normally used substitutes for this material.

Extensive tests just completed by independent researchers demonstrated this same point, as do other independent studies quoted at length in the manual.

Remember, there is no substitute for research. And there is no substitute for lifetime Vitrified Clay Pipe in your sewer lines.

* *Prepared by a Joint Committee of the Water Pollution Control Federation and the American Society of Civil Engineers, 1960.*



COMPRESSION SEALED, VITRIFIED
CLAY IMPERVIOUS PIPE
THE STANDARD in SANITARY SEWERS

NATIONAL CLAY PIPE MANUFACTURERS, INC.
1028 Connecticut Avenue
Washington 6, D. C.

NATIONAL CLAY PIPE MANUFACTURERS, INC.
1028 Connecticut Ave., Washington, D. C.

Please send me full details on the new factory-made compression joints on Clay Pipe.

(name)

(company)

(street address)

(city and state)

8-31 WP

DESIGN MANUALS

- **TREATMENT PLANT DESIGN**
- **SEWER DESIGN AND CONSTRUCTION**

COMPANION VOLUMES IN THE FEDERATION MANUAL SERIES

(Produced Jointly with ASCE)

"Sewage Treatment Plant Design," 374 pages of the latest information for those interested in plant design. (WPCF MOP 8).

"Design and Construction of Sanitary and Storm Sewers," the widely used sewer manual containing 283 pages of comprehensive information, including more than 100 illustrations. (WPCF MOP 9).

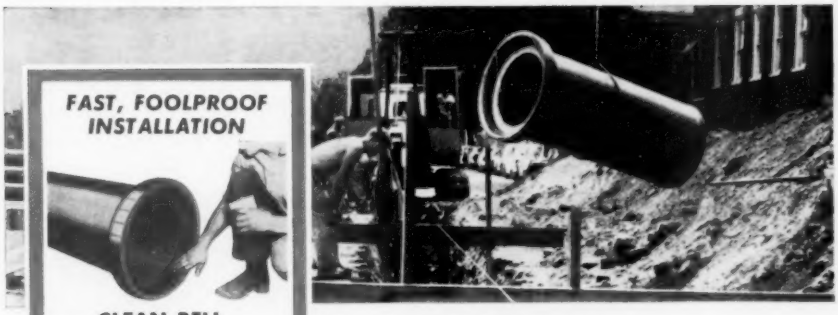
Each manual is offered to members at $3.50, and to others at $7.00.

Bring your reference library up to date with the addition of these authoritative volumes.

See Publications Page in this issue for other details and convenient order coupon.

WATER POLLUTION CONTROL FEDERATION

4435 Wisconsin Avenue Washington 16, D. C.



FAST, FOOLPROOF INSTALLATION

CLEAN BELL

CLEAN SPIGOT

PLACE RUBBER "O" RING IN SPIGOT GROOVE

LINE UP, SHOVE INTO PLACE THAT'S ALL THERE IS TO IT!

TODAY'S

FAST, TIGHT, TOUGH FACTORY-MADE JOINT

Wedge-Lock* Type "O"

BY ROBINSON

Now Available In Diameters Through 36"

Now, lines go in faster, seal tighter, stay trouble-free longer. Robinson Type "O" joints reduce laying time . . . cut installation costs . . . are ideally suited to difficult installation conditions. New precision-tight Factory-Made Wedge-Lock Type "O" joints handle infiltration and roots in any terrain.

THE **ROBINSON** CLAY PRODUCT CO.
ESTABLISHED 1856
AKRON 9, OHIO

*Patented. T.M. Reg. U.S. Pat. Off.

FASTER SERVICE

You get quick delivery of all sizes from strategically located Robinson branches.

FOR MORE DETAILS

on Robinson Factory-Jointed Clay Pipe, Call the Robinson Branch Office nearest you.

AKRON 9, OHIO
65 W. State St. PArtage 2-8601

ALBANY 4, N. Y.
1357 Broadway HObart 3-4139

BALTIMORE 2, MD.
1546 Mathieson Bldg. MUlberry 5-2930

BOSTON 34, MASS.
22 Pratt St., Allston Station STadium 2-8900

BUFFALO 10, N. Y.
1146 Seneca St. TRiangle 3082

CALDWELL TOWNSHIP, N. J.
Kulick Road (off Fairfield Road) CApital 6-8800

CHICAGO 46, ILL.
7100 N. Lehigh Ave., Edgebrook Sta. NEw Castle 1-5700

EAST HARTFORD 8, CONN.
170 Tolland St. BUtler 9-4389

INDIANAPOLIS 7, IND.
1013-15 E. 21st St. WAlnut 3-1507

NEW YORK, N. Y.
107-10 180th St., P. O. Box 589
Jamaica, L. I., N. Y. REpublic 9-7100

PHILADELPHIA, PA.
P. O. Box 85, Pottstown, Pa. FAculty 6-1310

ROCHESTER 11, N. Y.
609 Buffalo Road BEverly 5-6990

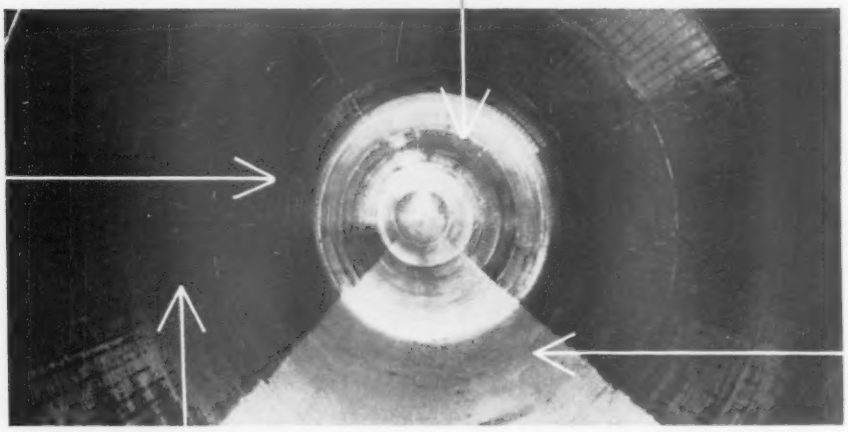
SYRACUSE 3, N. Y.
534 Spencer St. HArrison 2-9226

TORONTO, ONTARIO, CANADA
Baldwin Ave., Concord, Ontario, Canada AVenue 5-1138

YONKERS, Westchester County, N. Y.
1013 Saw Mill River Road YOnkers 8-7762

R 660 139

take a LONG LOOK at sewer linings



It's a Hundred Year Proposition

This 9½-foot outfall sewer extends eight miles, and it will go a long way in years of trouble-free service. The engineers who designed it say that it will still be functioning perfectly well into the 21st Century. One important reason is that every surface above the low flow line is completely covered by a continuous membrane of T-Lock Amer-Plate, the vinyl lining that is impervious to chemical effluents and to the corrosive action of oxidized hydrogen sulfide at any level of concentration.

Engineers know that no one can accurately predict future rates of H_2S gas generation, so they have insured the ultimate life of the concrete by investing an extra 8 to 10% for the absolute protection afforded by T-Lock. They predict that this will spare their city the cost of a replacement sewer in about 20 years, and save the taxpayers millions of dollars!

Where protection is required, only T-Lock is satisfactory because only T-Lock combines complete chemical imperviousness with integral T-ribbed back which mechanically locks into the concrete. Experienced sewer design engineers will not gamble on compromise methods. Millions of square feet of T-Lock are now in use in Los Angeles; Topeka; Wichita; Sioux City; Shreveport; Washington, D.C.; San Diego; Mansfield, Ohio; Huntington, W. Va.; Hutchinson, Kansas; and Orange County, Calif. T-Lock Amer-Plate is also on current specifications for many other municipalities. For complete list of users and specifiers, plus technical data and a typical specification, write:

Amercoat® CORPORATION

129A

Dept. SP, 4809 Firestone Blvd.
South Gate, California

921 Pitner Ave.
Evanston, Ill.

360 Carnegie Ave.
Kenilworth, N.J.

111 Colgate
Buffalo, N.Y.

2404 Dennis St.
Jacksonville, Fla.

6530 Supply Row
Houston, Tex.

FLUIDICS AT WORK

NOW... ANSWERS TO SOME OF YOUR QUESTIONS ABOUT LIQUID-SOLIDS SEPARATION

New bulletin gives useful facts on dissolved-air flotation unit.

"How can I get a high concentration of solids from a liquid suspension, for re-use or easy waste disposal?"

• • •

"Is there a way to get economical liquid-solid separation, when there are frequent variations in temperature, viscosity, pH, particle size, particle density, and entrainment concentration?"

• • •

"How does the Colloidair Separator keep heat loss to a minimum in the clarified liquid?"

• • •

You'll find answers to these and many other questions in our new Bulletin 4772.

Here, in six pages of facts and illustrations, you have a description of the design and operation of the Permutit Colloidair Separator — the dissolved-air flotation unit that eliminates almost all labor and supervision, and operates automatically and continuously.

If you are interested in this type of liquid-solids separation, we recommend that you study a copy of this bulletin. No obligation. Simply send the coupon below or drop us a note.

THE PERMUTIT CO. a division of Pfaudler Permutit Inc.
50 West 44th St., New York 36, N. Y.

Gentlemen:
I would like information on reducing operating costs and improving liquid-solids separation. Please send me your Bulletin 4772, "Permutit Colloidair Separator."

Name_____

Company or Municipality_____

Title_____

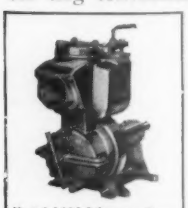
Street_____

City_____ Zone____ State_____

PFAUDLER PERMUTIT INC.
Specialists in FLUIDICS . . . the science of fluid processes

End Plate off *Towel out* *End Plate on*

"Towels can jam the works, but good!" says Cecil Kent, owner, Sanitation Service Company, Jacksonville, Florida. "I've had 'em clog conventional pumps so bad, it meant a shutdown from two hours to two days.



Model 14A2-B Sewage Pump

"That's why I've standardized on Gorman-Rupp sewage pumps. And what a difference! Fewer shutdowns . . . clogging cleared in just three to fifteen minutes! This cuts average maintenance costs from $120 to only $12 per pump per year. On my 21 Gorman-Rupp pump installations, that adds up to a whopping big saving. Over $2200 a year on parts, packing, materials, and labor.

"Sure, I had a problem—but no more!"

Thrifty, trouble-free, self-priming Gorman-Rupp sewage pumps—2″, 3″, 4″ or 6″ sizes—can be connected to your power or ordered complete with power units. Write for complete specifications.

THE GORMAN-RUPP COMPANY

305 Bowman Street **Mansfield, Ohio**

Gorman-Rupp of Canada Ltd., St. Thomas, Ontario

11-2207

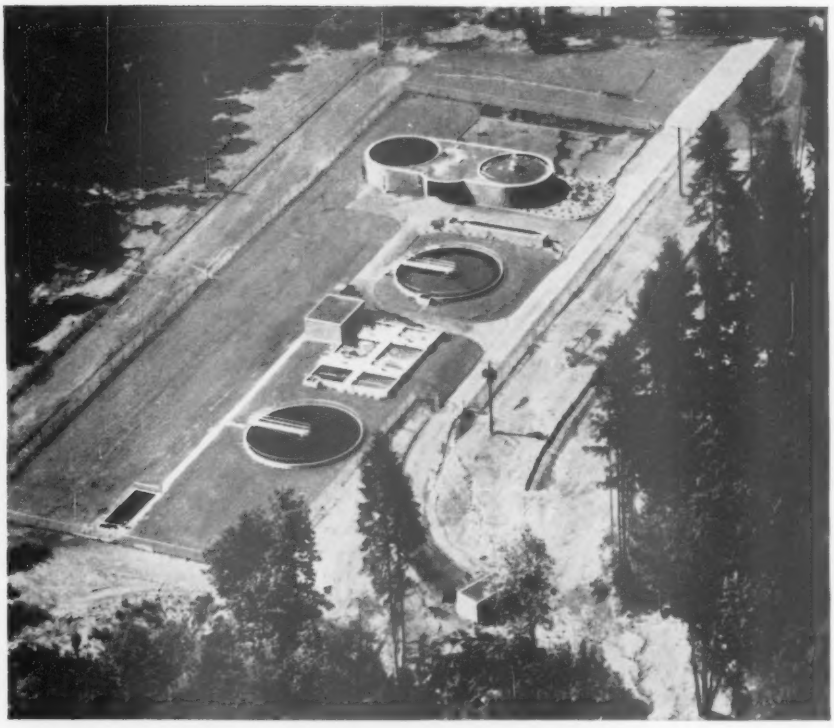
Hardly! You see, Transite®, the *white sewer pipe*, is made of ageless minerals—asbestos and cement. The asbestos fibers, each with the tensile strength of piano wire, reinforce the cement to form a stone-like pipe that is rugged, tough and durable. Transite is also steam-cured under high pressure, adding further to its strength, durability and chemical stability. And, being non-metallic, there's no chance of oxidation weakening its structure. What's more, Transite's high crushing strength can withstand the heavy overburden, ground movement and earth shocks that continually challenge the ability of sewer pipe. When you add to this Transite's long lengths, tight joints and naturally smooth interior, it becomes obvious that this white sewer pipe was designed to offer greater total life expectancy.

For all the facts, write for special data file. Please indicate if you are a city official, engineer or contractor. Address: Johns-Manville, Special Sewer Data, Box 14, JW-4, New York 16, N. Y. In Canada: Port Credit, Ont. Cable address: Johnmanvil.

The Transite Pipe shown in this 23-year-old photo is still providing trouble-free service.

JOHNS-MANVILLE
TRANSITE SEWER PIPE

JM



Hillsboro, Oregon, adopts Activated Sludge Treatment with

D-O AERATORS

A high degree of treatment, made necessary by minimum river flow during the summer and the presence of parks, picnic grounds and swimming areas downstream, is achieved in this 1.25 MGD activated sludge plant for the City of Hillsboro, situated west of Portland, Oregon. Overall B.O.D. reduction is well in excess of 90%.

Key to successful operation is the use of the D-O Aerator – a radically new design providing exceptionally high oxygen absorption efficiency, with virtually no problems of clogging and maintenance. Treatment units include 45′ dia. Dorr Primary and Final Clarifiers and four D-O Aerators. Two Aerators are installed per basin. Each basin is 56′ long x 18′6″ wide x 15′ s.w.d. to provide a liquid design detention of three hours. For information on the new D-O Aerator, write for Bulletin No. 7316 to Dorr-Oliver Incorporated, Stamford, Connecticut.

Consulting Engineers: Stevens and Thompson, Portland, Oregon.
Contractor: Lloyd B. Reed, Portland, Oregon.

DORR-OLIVER

WORLD-WIDE RESEARCH • ENGINEERING • EQUIPMENT

EFFECT OF PREAERATION ON THE PRIMARY TREATMENT OF SEWAGE

Harris F. Seidel and E. Robert Baumann

Preaeration is not a new idea in sewage treatment; in 1933 Roe (1) described nine plants in the Midwest and two in California incorporating this treatment step. Nevertheless, it remains a misunderstood and controversial waste treatment process.

In this investigation, the term preaeration was restricted to an air agitation pretreatment of raw sewage for a period of 30 to 45 min prior to primary settling, without either the addition of chemicals or the return of final settling sludge, digester supernatant, or any other material which might serve as a physical or biological aid to flocculation.

The value of preaeration, even after years of use, remains open to argument. Its proponents assert that preaeration accomplishes flocculation which significantly benefits primary settling and thus increases primary BOD and suspended solids removal. Other advantages claimed for the process are:

1. Grease flotation,
2. Grit separation,
3. Freshening or improved treatability in biological secondary treatment,
4. Addition of dissolved oxygen,
5. Scrubbing of noxious gases and odor,
6. Nominal BOD satisfaction, and
7. Mixing and dispersal of waste "slugs."

The purpose of this investigation was to evaluate the influence of preaeration on primary settling efficiency, to study the factors affecting this influence, and to evaluate the economic worth of the preaeration process. The work was done in full-scale operation of the Ames, Iowa, municipal sewage treatment plant.

Harris F. Seidel is Director of Water and Sewage Treatment, Ames, Iowa. E. Robert Baumann is Professor of Civil (Sanitary) Engineering, Iowa State University, Ames, Iowa.

Development and Present Status

Rutgers

The thirties witnessed strong interest in chemical treatment as a basic sewage treatment process. Important research along these lines was reported by Rutgers University; one paper (2) discussed laboratory results on flocculation alone without chemicals, both by mechanical stirring and by air diffusion. It was reported that air and mechanical flocculation produced like removals in the absence of coagulants. It was also found that mechanical stirring, even in the presence of coagulants, could be too vigorous, resulting in poorer ultimate removal. The use of coagulants gave substantially better removals than flocculation alone.

In a later publication (3), results of flocculation experiments conducted in atmospheres of air, ozone, oxygen, carbon dioxide, and nitrogen were reported. The test runs were designed with gentle mixing for periods of 0.5, 2 and 5 hr, each followed by 2 hr settling. Improvement over plain settling was noted, though the gas used made little difference.

In a subsequent run, the above gases, along with hydrogen peroxide, were diffused directly into sewage samples in what was apparently the first considered observation of preaeration. It

was stated that this procedure gave even greater improvement over plain settling.

Dorr

During the mid-thirties, the Dorr Company conducted an extensive research study of mechanical flocculation (4). Laboratory tests were made at nine sewage treatment plants from Connecticut to the Dakotas, followed by plant-scale work at Cedar Rapids, Iowa (5), and Ypsilanti, Mich.

In the laboratory tests, flocculation was found to improve primary settling efficiencies. Flocculation was also found to accelerate settling; that is, considerably more of the ultimately settleable material was removed in early time increments than was the case with plain settling. Correspondingly, the margin of improvement shown by flocculation was greatest with short settling time and decreased with extended settling. The degree of improvement did not seem to be affected by strength of the waste.

At Cedar Rapids, suspended solids removal averaged 54 per cent by plain settling and 64 per cent by flocculation and settling, a gain of 10 percentage points or an 18 per cent improvement. BOD removals were poor and erratic, but were improved from about 13 per cent to about 20 per cent by flocculation. The improvement by flocculation was no greater for the stronger wastes, but was, if anything, less because these wastes responded so well to plain settling. As expected, increased flocculation time added to the degree of improvement.

At Ypsilanti, plant-scale results again indicated a significant advantage for flocculation and settling over plain settling.

Europe

Mechanical flocculation also received its share of attention abroad. In 1942 preflocculation was said to have given excellent results in England (6). In 1943, laboratory and operating data were reported from Germany (7). The floc formed was fragile and tended to break up at flow velocities exceeding 1.3 fps. In 1949, seven years of full-scale operation were reported for Wolverhampton, England (8), in which a Clariflocculator gave 20 per cent better removal than a conventional clarifier of the same over-all dimensions.

Operating Experiences

Mechanical flocculation is generally accepted; yet preaeration remains controversial. Although it is said to offer such extra dividends as odor control, grease flotation, grit washing, and improved treatability, there is wide disagreement on whether or not preaeration also improves primary settling removals, as seems quite well established for mechanical preflocculation.

Favorable operating experiences with preaeration have been reported by Currie (9), Walker (10) and Lee (11). At Wichita, Lee described the results of a five-week test period without the normal 1.8 hr preaeration ahead of primary settling. BOD removal averaged only 34 per cent during the test period, while averaging 40 per cent for three weeks prior and 42 per cent for the two weeks following. Suspended solids removal averaged 64 per cent without preaeration and 67 and 69 per cent, respectively, before and after the test period.

On the other hand, unfavorable operating experiences have been reported by Gunson (12) and Mann (13). Further, the results at Hyperion as described by Bargman *et al.* (14) are of particular interest here.

Sewage reaches the Hyperion plant in Los Angeles after many miles and hours of flow, high in temperature, high in sulfides, high in immediate oxygen demand, and strongly anaerobic. With this waste, the 0.5 hr preaeration provided ahead of primary settling has been of no value other than for corrosion control.

Valuable work has been done at

Hyperion in correlating ORP with sewage characteristics and particularly with microbiological conditions in terms of aerobic, facultative, or anaerobic environment. The degradation of the raw sewage has progressed so far that, while preaeration raises it to a facultative state, the sewage is again anaerobic on leaving primary settling. Despite a large air-supply rate to the aeration tanks, the sewage does not even remain aerobic during final settling. The following quotation provides a valuable insight into the concept of treatability:

> A careful and detailed study of the preaeration system was made as it affected the primary sedimentation effluent. One-half of the sewage flow was given preaeration, while the other half received none. The primary sedimentation effluent from the preaerated half was the same as the effluent received from the unpreaerated half insofar as BOD, suspended solids, settleable solids, and chlorine demand reduction were concerned. Preaeration did reduce the sulfide content somewhat, thus reducing the oxygen demand of the aerator influent a small degree. It is doubtful that the slight reduction in oxygen demand justifies the use of air for preaeration, and it is felt that the air would be used to better purposes in the aerators. In contradiction to this, preaeration has apparently been of value in other installations.
>
> It is believed that the concept of treatability can help to explain why preaeration works at some locations and fails at others. Preaeration of sewage which is only slightly septic and has a low to moderate oxygen demand might keep the sewage in the high facultative to low aerobic range, preventing anaerobic breakdown, and thus decrease the load on the aerators. However, where the septicity is far advanced and the oxygen demand is high, a short preaeration period cannot meet the oxygen demand, and the little good accomplished by preaeration is quickly nullified by further anaerobic degradation in the primary sedimentation tanks.

Survey by Roe

The first solid survey and discussion of preaeration practice was published in 1951 by Roe (15). The survey failed to turn up a single set of comparative plant data in which plain settling was operated in parallel with the combination of preaeration and settling. Nevertheless, it was a valuable review of the art as then known.

The survey returns were unanimous in reporting odor control and at least some attack on septicity by preaeration. Of the 51 plants reporting, 18 indicated that grease removal was considered in the design of the preaeration unit, but only six gave data on actual grease removal. In addition, five plants reported grit removal by preaeration, although only three were so designed.

With regard to the critical factor of improved primary treatment, suspended solids removal by preaeration and 2 hr settling were reported to improve substantially with increased preaeration time. BOD removal reported by 26 of the plants showed no correlation; it can only be theorized that, if preaeration does result in improved suspended solids removal, BOD must also be affected simply by reduction of the amount of solids in the primary effluent. The rate of aeration was found to vary generally from about 0.07 cu ft/gal for 10 min preaeration to about 0.16 cu ft/gal for 60 min preaeration. These rates represent, of course, actual practice rather than design criteria.

Present Status

To determine current design policies, 15 Midwest and Great Lakes states were canvassed. Of the 15, 14 indicated a willingness to give some credit for increased primary removal following preaeration. The restrictions and qualifications specified varied from mild to rigorous; no two states approached this with the same viewpoint. The allowance for increased BOD removal beyond a suggested 35 per cent for plain settling varied from 0 to 15 additional percentage points.

First, it is apparent that one can take any position whatever on preaeration and find company. Just as operating reports conflict, comments

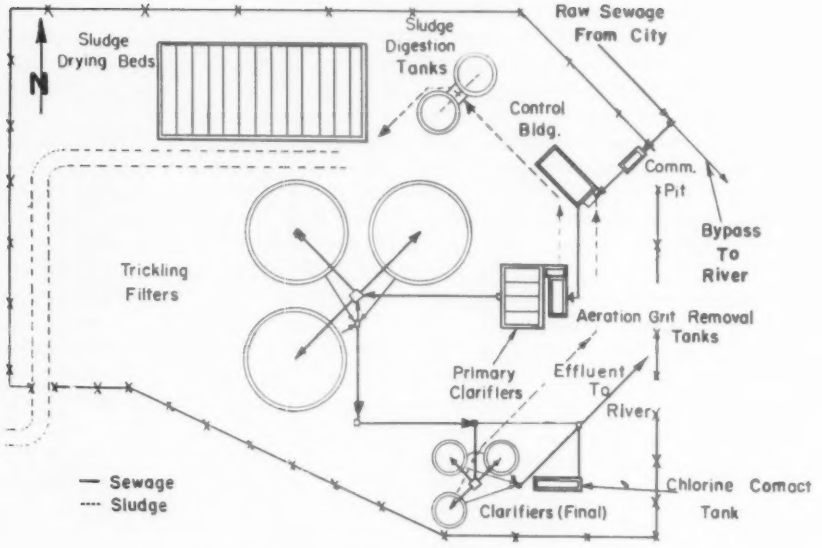


FIGURE 1.—Layout of Ames, Iowa, sewage treatment plant.

and opinions of those in the field vary from enthusiasm to disillusionment.

Some engineering firms include preaeration in all or most of their plant designs; others ignore it. Equipment firms report that interest in preaeration is high, but that for no other treatment step does design practice vary so widely.

The following quotation can be repeated today with authority (16): "... preaeration facilities are provided in many modern plants, yet there are almost no data on the true advantages and limitations of the process." Over 200 plants in this country now include this treatment step; yet comparative, parallel operating data with and without preaeration are lacking.

Description of Ames Plant

The Ames plant (Figure 1) is designed to treat an average flow of 3.0 mgd. Actual flow to the plant during this project ranged generally from 2.1 to 2.8 mgd. The population served is about 27,000. Sewage strength in terms of both BOD and suspended solids normally averages from 200 to 250 mg/l; over-all plant removals range from 75 to 80 per cent in winter to about 90 per cent in summer. Float tests indicate that daytime sewage flow from the main business district reaches the plant in roughly 1¼ hr, while the flow time from Iowa State University is approximately 2 hr.

Treatment units and normal plant operation are described in detail in the other reports (17) (18). Basically, the plant is of standard-rate trickling filter design, with rectangular primary clarifiers, circular final clarifiers, and separate sludge digestion. The preaeration tanks (Figure 2) were originally equipped with down-draft aerators; these tanks also provide grit removal. Following initial pumping, gravity flow is provided throughout the plant.

Preliminary Plant Studies

September 1956–March 1957

During this rather long period of preliminary operation, incoming flow

was split accurately; half received preaeration followed by primary settling, while the other half was bypassed directly to plain primary settling. No return of final settled sludge or digester supernatant was made during sampling periods.

The results of this plant-scale run were enlightening. While preaeration and primary settling produced the expected removals, plain settling results deteriorated steadily; for weeks at a time, suspended solids removals were at a level of 15 to 25 per cent, while plain primary effluent BOD strength at times exceeded that of the incoming raw sewage.

The cause for this severe upset, as later determined by inspection, sampling, and further runs, was grit. Without the grit removal usually afforded by the preaeration unit, a certain fraction of rather coarse grit succeeded in building impressive and unbelievably solid banks of grit in the sludge hopper area of the north primary clarifiers. These grit banks had a high content of putrescible material. This digesting mass apparently was sufficiently active to poison the entire clarifier to the extent described.

July 1957

With the cause of the very poor results from plain settling known, fur-

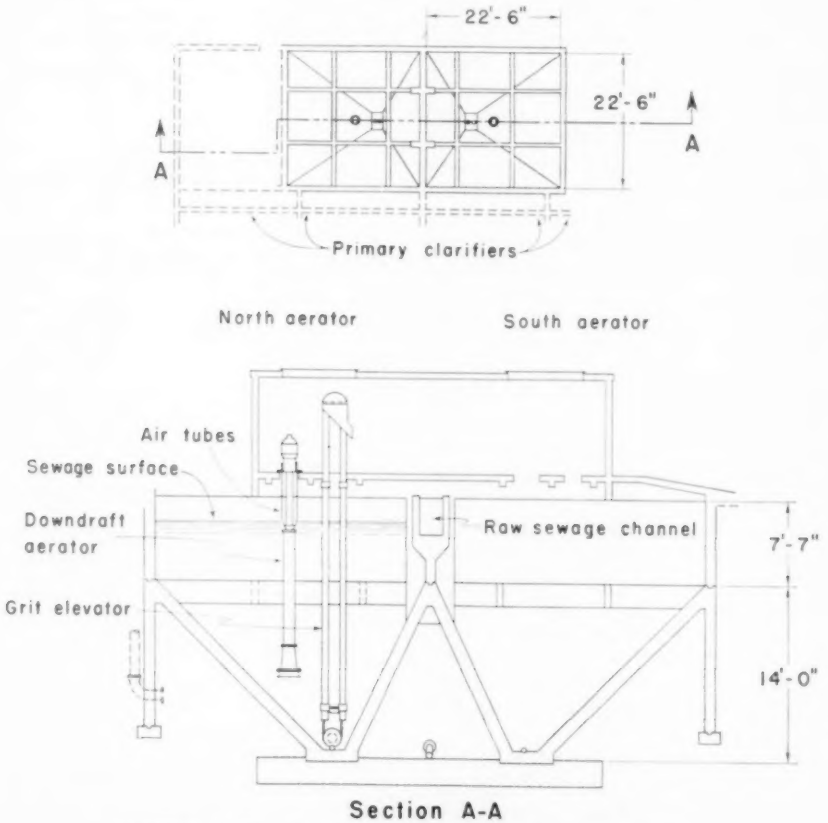


FIGURE 2.—Plan and section through Ames' preaeration tanks.

TABLE I.—Summary of July 1957 Ames Plant Results

Date and Day	Flow (mgd)	Mean Sewage Temp. (°F)	Avg Primary BOD Removal (%)		Avg Primary SS Removal (%)	
			Plain	Preaerated	Plain	Preaerated
9 Tu	2.92	70	29.1	40.1	68.2	77.5
10 W	2.88	70	27.1	37.2	60.0	70.5
16 Tu	2.76	71	35.6	44.3	64.4	65.8
17 W	2.70	70	40.8	46.2	53.3	59.8
23 Tu	2.65	70	32.2	36.9	57.6	67.8
24 W	2.44	71	45.5	53.9	65.3	71.6
30 Tu*	2.96	72	36.3	30.7	33.3	38.0
31 W*	2.65	72	30.3	46.9	33.7	42.9

* Local corn cannery in operation.

ther plant runs were made with special precautions to eliminate this factor.

The July test run involved 24 hr sampling each Tuesday and Wednesday for four weeks. In preparation for the sampling period, the following routine was observed. On Monday morning, the sludge hoppers in all four primaries were jetted free of grit and sludge while the primaries remained in service. On Monday afternoon, digester and sludge-well supernatants were diverted to the sludge lagoon, and final sludge recirculation was shut down. One preaeration unit was bypassed, and the plant received no return flow of any kind until conclusion of the two-day sampling period.

The plant-scale comparative data indicated consistent and significant improvement in primary removals following preaeration. Detailed BOD and suspended solids results are summarized in Table I. For the first three weeks, average primary BOD removals were 35 per cent without preaeration and 43 per cent with preaeration. Comparable suspended solids removals were 61 and 69 per cent, respectively. Removals were much lower the fourth week, but the improvement due to preaeration was still significant in spite of the added cannery waste.

For this waste at this plant during this month, preaeration produced significantly better primary removals than did plain settling.

Laboratory-Scale Studies

To supplement the work being done on plant scale, extensive tests were made in the laboratory with groups of 1-gal samples. This work centered on the effect of preaeration time, and on the length of settling time following preaeration.

Varied Preaeration Time

In tests with preaeration times of 15, 30, 45, and 60 min, it was apparent that longer aeration was of increased benefit. Assuming ultimate improvement from the 60-min period, about half the expected improvement was achieved in the first 15 min, and over 80 per cent in 45 min. This, of course, was in the laboratory under ideal conditions, without the short-circuiting or similar problems encountered in plant operation.

There was no indication that strong sewage was benefited more than the weak. However, the poorer the job done by plain settling, the greater the benefit from preaeration. If this were valid in actual plant operation, preaeration would be unusually helpful.

Varied Settling Time

Further laboratory tests were run holding preaeration time constant and varying settling time from 0.5 to 4 hr. It appeared that preaeration strongly enhanced the efficiency of the early

moments of settling. Again making an arbitrary assumption that ultimate benefit accrued from 4-hr settling, 73 per cent of this benefit was achieved in the first 30 min, 85 per cent in 1 hr, and over 90 per cent in 2 hr. Compositing all laboratory runs, it can be shown that 30 min preaeration followed by 30 min settling outperformed plain settling of 2 or even 3 hr duration. Similarly, 60 min preaeration with 30 min settling was roughly equivalent to 15 min preaeration and 3 hr settling, and quite superior to plain settling of 4 hr duration or longer. Complete data are presented in the final project report (17).

In these terms, preaeration appears very attractive. It also appears that the key to its optimum use may be in the judicious substitution of preaeration detention time for settling detention time. Finally, it must be cautioned that there are wide and numerous gaps between what can be done in the laboratory and what can be done in full-scale plant operation.

Laboratory and Test Procedures

A good deal of time was spent in refining sampling and laboratory techniques specifically adapted to this project. Detailed description, sketches, and examples are presented in the final project report (17) and will be noted here only in passing.

Oxygen Values

Dissolved oxygen determinations followed the Winkler method except for the substitution of a direct photometric reading instead of titration following color development. This procedure has been previously described (19). BOD determinations also followed "Standard Methods" (20), with the exception just noted.

To learn something about the rate of short-term oxygen demand of raw sewage upon its arrival at the plant, several simple experimental methods were tested. The result was a procedure which consisted of violently agitating a sewage sample to a DO level of 6 or 8 mg/l, then observing the rate of DO depletion over a period of 45 min to an hour.

After agitation, a series of small bottles was filled immediately by siphon from the sewage sample. The DO level was then determined in one bottle at a time at 5 or 10 min intervals. The result was a series exhibiting decreasing color intensity, and thus DO content, with time. For normal daytime raw sewage, the rate of DO depletion was in the range of 5 to 8 mg/l/hr. The normal rate for primary effluent was found to be in the range of 2 to 4 mg/l/hr.

This determination was helpful in evaluating the rate of oxygen acceptance during the preaeration step. If the raw sewage neither gained nor lost DO during preaeration, its oxygen demand rate was just being met, and the depletion test then provided a numerical measure of the rate of both demand and supply. If the DO level rose or dropped en route through preaeration, the rate of acceptance could be approximated by taking into account probable detention time. Although not particularly scientific, this test contributed an understanding of the aeration phase of preaeration which would not have been possible otherwise.

Solids Determination

In addition to determination of suspended solids by evaporation, a rapid and sufficiently reliable photometric procedure was developed. This made it possible to carry on a repetitive sampling program which would otherwise have been physically impossible.

Settling Rate

Early in this project it was theorized that if preaeration were of benefit to primary treatment, it would stimulate flocculation of the raw sewage solids and thereby accelerate settling. Several experimental photometric arrange-

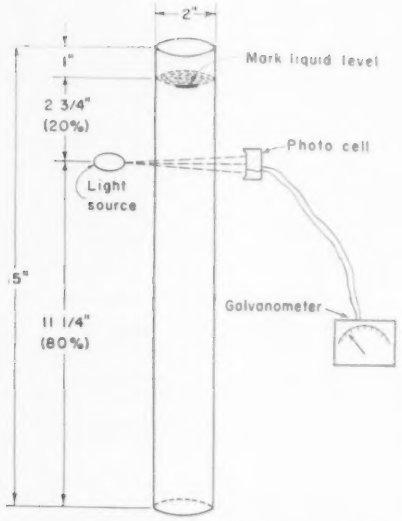


FIGURE 3.—Functional sketch of Oulman settlimeter.

ments were tested for observing the settling rate; the result was a device which was subsequently termed the Oulman settlimeter. Its functional design is shown in Figure 3.

In practice, a sample of sewage was collected in a 2-in. diam settling cell and placed in the cell holder. As settling progressed, light transmission through the cell increased. This was measured by the photocell and indicated by the galvanometer. More rapid settling was readily apparent by more rapid change in galvanometer readings.

Comparative settling rates were observed by sampling preaeration influent and preaeration effluent, spaced by a time interval representing probable mean detention time in the preaeration tank. A method was developed for conversion of galvanometer readings to mg/l of suspended solids, by means of supplemental solids determinations. The settlimeter proved reliable in predicting and checking actual plant performance in full-scale runs at the Ames plant. It was particularly valuable in pointing up the effect of preaeration on the early moments of settling.

Aeration Devices

The blower used for this project was rated at 200 cfm against 7 psi pressure, but was able to perform above its rated capacity.

Plant-scale studies began with the original down-draft aerators. This unit consists basically of a 5-hp motor driving a turbine impeller operating at a shallow liquid depth. As the impeller revolves, air is drawn through suction tubes to the impeller area, and this air-sewage mixture is pumped down through a draft tube to the lower tank area. Both recirculation and some aeration of the tank contents are achieved. The major source of energy for tank recirculation is pumping; this equipment was, of course, operated without the blower.

Next, plant runs were conducted with aeration provided by spargers. Sixteen were mounted in a grid pattern in the south preaeration tank at a depth equal to the outlet of the down-draft tube. A number of runs were made with all sixteen in service; further runs were made when half were sealed.

Diffusion tubes were also used for aeration; those provided for this study were stock units for use in diatomite filtration of water. Each diffusion tube was of a high-impact styrene core, 3½-in. OD and 3 ft in length, with a sock-type covering of Dialon, a monofilament polyethylene material.

It is pointed out that with the spargers and diffusion tubes all the energy for tank recirculation was provided by the air alone. For blower operation, it appeared that an air rate of 40 to 50 cfm was the minimum required for maintaining recirculation of the tank contents.

Plant-Scale Studies—1958

Plant Operation

Arrangement of the plant units was substantially the same as for the July 1957 test series. Incoming raw sewage flow was split, half bypassing directly to the north primary clarifiers, while

the other half was directed to the south preaeration unit and then to the south primaries. All four primaries were operated in a normal manner, with sludge withdrawal at 6-hr intervals.

The three trickling filters and three final clarifiers were in operation throughout the 1958 test series. Final settling sludge was held in the final clarifiers during the week and run back to the raw sewage wet well only on week ends. Digester and sludge-well supernatants were drained to the sludge lagoon throughout these runs. These arrangements were designed to provide for the operation of the primary treatment units without recirculation or return of material of any kind to the raw sewage.

To avoid a recurrence of the grit problem which so thoroughly disrupted the first plant runs, the primary sludge hoppers were jetted free of sludge and grit each Monday morning. At the same time, the south preaeration unit was completely emptied and flushed down. These precautions were successful in eliminating any accumulation of grit or septic sludge during these runs.

Plant studies were begun with the original down-draft aerator in place in the south preaeration tank. A number of replicate runs were made with this aerator operated at natural draft of about 12 cfm, with the air intake throttled to about 8 cfm, and with the draft tubes capped to exclude any aeration in the normal manner. With the draft tubes capped, the only aeration was through surface agitation.

Following installation of the spargers and diffusion tubes in the preaeration units, plant studies were conducted with these devices at aeration rates of from 65 to 200 cfm. Raw sewage flow to the plant during the 1958 studies averaged roughly 2.4 mgd. The south

TABLE II.—Typical Ames Plant Oxygen Results

Date and Day (1958)	Preaeration Arrangement	Air Flow (cfm)	Inflow Sampling Time (PM)	Inflow Rate (mgd)	Dissolved Oxygen Levels in Preaerator (mg/l)		Observed Depletion Rate (mg/l/hr)	Calculated Acceptance Rate (mg/l/hr)	Oxygen Transfer Efficiency* (%)
					Influent	Effluent			
3/24 M	down-draft	12	2:10–3:30	3.0	−0.2	1.2	6	9	20
3/25 Tu	down-draft	12	1:00–3:00	3.1	1	2.5	6.5	9.3	21
4/4 F	down-draft	12	2:30–3:30	2.8	1	2	—	—	—
4/5 Sa	down-draft	12	1:30–3:00	2.7	1	3	—	—	—
4/12 Sa	down-draft	0	2:00–3:20	3.2	1	−2	—	—	—
4/19 Sa	down-draft	8	3:00–4:30	3.1	0.0	0.8	5.5	7.1	24
4/26 Sa	down-draft	8	1:40–2:40	3.3	0.4	1.8	5.0	7.8	26
5/9 F	16 spargers	125	2:20–2:50	3.4	0.1	1.9	6.8	10.6	2.3
5/10 Sa	16 spargers	200	2:20–3:40	3.2	0.2	2.8	6.2	12.2	1.6
6/16 M	16 spargers	65	2:20–3:20	3.1	0.6	−0.2	6.5	4.6	1.9
6/17 Tu	16 spargers	65	2:40–3:40	3.0	0.6	0.2	6.8	6.0	2.5
6/18 W	16 spargers	100	3:00–4:00	3.1	0.0	0.0	6.1	6.1	1.6
6/19 Th	16 spargers	100	2:40–3:40	3.2	0.4	0.4	6.3	6.3	1.7
6/20 F	16 spargers	150	2:40–3:40	2.9	0.2	2.3	6.3	10.1	1.8
6/21 Sa	16 spargers	200	2:40–3:40	2.7	0.2	1.8	6.7	10.0	1.3
6/24 Tu	8 spargers	65	2:30–3:30	2.9	0.2	−0.1	5.2	4.7	1.9
6/25 W	8 spargers	65	2:20–3:20	3.0	0.3	0.2	6.6	6.2	2.5
6/26 Th	8 spargers	100	2:20–3:20	2.9	0.2	0.8	6.3	7.3	1.9
6/27 F	6 spargers	150	2:20–3:20	2.9	0.6	2.1	6.7	9.4	1.7
6/28 Sa	8 spargers	200	2:20–3:20	2.8	0.1	2.4	6.7	10.7	1.4
6/30 M	down-draft	12	2:00–3:00	3.2	0.0	−0.2	7.5	7.1	16

* Assuming no surface aeration.

TABLE III.—Ames Plant Oxygen Transfer Efficiencies

Preaeration System	Aeration Rate		Average Oxygen Transfer Efficiency (%)	
	(cfm)	(cu ft/gal*)	Assuming No Surface Aeration	Deducting Effect of Surface Aeration†
Down-draft	8	.007	25	10
	12	.011	20	10
Spargers	65	.054	2.2	1.2
	200	.18	1.4	1.1

* Calculated for 3.2 mgd daytime flow.

† Surface aeration estimated to contribute 4–5 mg/l/hr during down-draft operation; 2–3 mg/l/hr during sparger operation.

preaeration tank provided a theoretical displacement time of 48 min at the 2.4-mgd average flow rate. Blower aeration rates, based on the 2.4-mgd flow, ranged from 0.08 cu ft/gal at 65 cfm to 0.24 cu ft/gal at 200 cfm.

Sampling Procedure

Sampling began at four points at 10:30 AM and continued through 9:30 PM. The samples were composited generally in step with flow-through times. The result was a reasonably faithful record of the same 10-hr flow as it received primary treatment.

All samples were collected in 250 ml square, wide-mouth bottles and stored in a 4°C water-bath cooler. After compositing in proportion to flow, photometric suspended solids determinations were made on each individual sample. Sampling for DO levels and oxygen depletion rates was confined to mid-afternoon when sewage flow and strength were reasonably constant.

Plant-Scale Results

Oxygen Values

In Table II are summarized oxygen values representing mid-afternoon conditions. Raw sewage reaching the plant in mid-afternoon was always low in DO, usually 0.5 mg/l or less, but rarely past the point of depletion to a state of negative DO. After preaeration, the DO level was less, sometimes negative, at low aeration rates, roughly the same at moderate aeration rates; and 2 to 2.5 mg/l higher at maximum aeration capacity of 200 cfm.

From observations on preaeration influent and effluent DO levels and DO depletion rates, it was possible to calculate the rate at which DO was being accepted by the sewage during preaeration. Even under the maximum air rate of 200 cfm, this rate of acceptance did not exceed 10 to 11 mg/l/hr, or roughly twice the usual depletion rate. Finally, the aeration or oxygen transfer efficiency was calculated in terms of the per cent of mechanically supplied oxygen which was accepted by the sewage during preaeration.

Analysis of the calculated oxygen transfer efficiencies proved interesting. Assuming first that all the oxygen accepted by the sewage was introduced by the aeration equipment, efficiencies for the down-draft aerator ranged from 20 to 25 per cent, but for the spargers only about 1½ to 2 per cent. The calculated efficiency in each case fell as the aeration rate was increased.

Close inspection of the data revealed that oxygen acceptance did not increase proportionally with aeration rates. This implied that oxygen was also being absorbed by the sewage simply through surface agitation. Actually, this has long been known to occur, and was further confirmed by data from down-draft aeration runs with the air-draft tubes completely capped.

Even at full natural draft, surface aeration apparently accounted for

about half the oxygen transfer achieved by the down-draft equipment. The same relationship was indicated for the spargers and diffusion tubes at the 100-cfm aeration rate. At lower aeration rates, surface transfer was of more benefit than sub-surface diffusion. Table III presents a summary of aeration rates and calculated oxygen transfer efficiencies, with and without allowance for surface aeration. It is particularly interesting to note that, when surface aeration is evaluated separately, calculated transfer efficiencies are essentially constant regardless of aeration rate. In a physical rather than biological process such as this, such a finding appears reasonable.

The important lesson from this work on oxygen values may be that it is not possible to transfer DO in more than token amounts to the sewage at this point because the oxygen demand, in the form of active biological life and a corresponding food supply, simply does not exist. To maintain the incoming DO level during preaeration, an aeration rate of about 0.1 cu ft/gal is indicated for the Ames plant. Regardless of the preaeration method, surface agitation appears to be an important source of oxygen transfer.

Oxidation-Reduction Potential

The oxidation-reduction potential is a measure of the tendency of a physical or chemical system to yield electrons (oxidation) or to gain them (reduction). Since most bacterial cultures are reducing systems due to the metabolism of their organisms, raw sewage is either negative in potential or becomes so rapidly upon depletion of its original DO content. The more highly reducing a system, the greater will be its negative potential. Correspondingly, a rapid change in potential indicates a high rate of bacterial metabolism.

At the Ames plant, the daytime raw sewage ORP, based on a few days' work in December 1958, ranged 20 to 30 mv on either side of neutral. Its rate of change in the negative direction was 30 to 50 mv/hr, and this rate of change was essentially unaffected by preaeration or by primary settling. Following secondary treatment, however, the ORP level was found to be in the range of + 200 mv, and its rate of change only 15 to 20 mv/hr, although still in the negative direction. These results, along with a DO level of 6 to 8 mg/l, confirm the character of the final plant effluent as a fairly stable, highly oxidized system.

Preaeration was found to boost ORP levels slightly in the positive direction even when failing to maintain DO constant. When a high aeration rate increased the DO, it raised the ORP to a sufficiently positive level to survive primary settling without reverting to a negative potential. Whether or not this is economically justified in terms of improved secondary-stage treatment is problematical.

Settling Characteristics

The objective here was to reflect in the laboratory actual settling performance in the plant. The Oulman settlimeter met this objective.

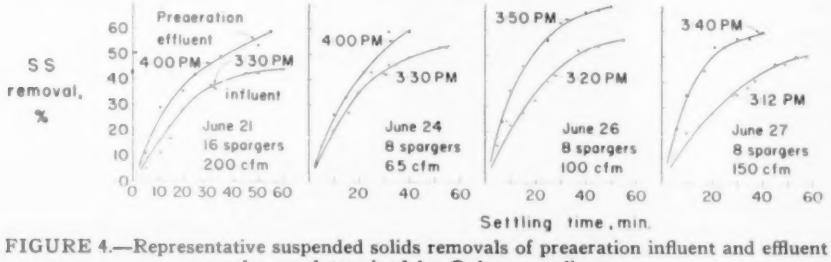


FIGURE 4.—Representative suspended solids removals of preaeration influent and effluent samples, as determined by Oulman settlimeter.

TABLE IV.—Typical Plant-Scale Results

Date and Day (1958)	Sewage Flow (mgd)	Preaeration Arrangement (No. of spargers)	Air Flow (cfm)	Composite Sampling Period (hr)	Sewage Strength (mg/l)								Primary Removals* (%)			
					Preaeration				Primary Effluent				BOD		SS	
					Influent		Effluent		Plain Settling		Preaeration		Plain Settling	Preaeration	Plain Settling	Preaeration
					BOD	SS	BOD	SS	BOD	SS	BOD	SS				
6/16 M	2.41	16	65	8	196	223	202	217	162	82	124	69	18.6	37.7	62.7	68.6
6/17 Tu	2.26	16	65	10	214	—	206	—	130	—	128	—	38.1	39.0	—	—
6/18 W	2.30	16	100	10	252	247	244	221	180	82	169	72	27.4	32.4	64.9	69.2
6/19 Th	2.37	16	100	10	210	205	205	181	189	72	180	57	8.9	13.3	62.7	70.5
6/20 F	2.21	16	150	10	220	234	213	222	140	81	120	54	35.3	44.5	64.5	76.3
6/21 Sa	2.05	16	200	10	235	233	235	239	140	91	135	67	40.4	42.5	61.4	71.6
6/24 Tu	2.17	8	65	10	210	191	210	180	136	74	120	56	33.7	41.5	60.1	69.8
6/25 W	2.16	8	65	10	206	208	228	200	156	78	122	63	28.1	43.8	61.7	69.1
6/26 Th	2.15	8	100	10	210	225	195	210	159	90	150	69	21.5	25.9	58.5	68.2
6/27 F	2.20	8	150	10	—	222	170	215	118	80	108	61	30.6	36.5	63.4	72.1
6/28 Sa	2.13	8	200	10	180	252	—	254	—	97	—	70	—	—	61.7	72.3

* Calculated removals based on average of preaeration influent and effluent strengths.

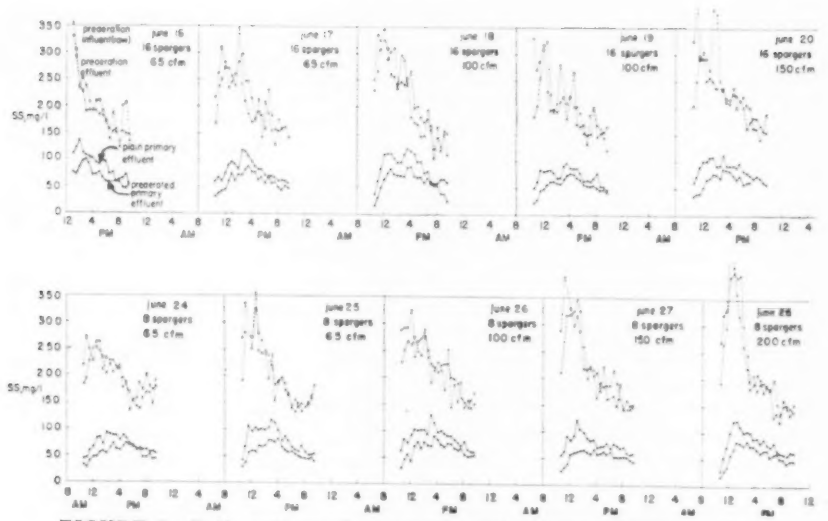


FIGURE 5.—Daily patterns of raw sewage and primary effluent suspended solids concentrations.

Several typical plots of paired settlimeter data are shown in Figure 4. Each consists of the settling curve for a preaeration influent sample and a matching curve for a preaeration effluent sample collected following a time interval considered to be the probable mean preaeration detention time.

On the days shown, during which plant suspended solids removals were consistently being boosted 10 percentage points by preaeration, the settlimeter plots also indicated from 8 to 12 percentage points higher suspended solids removal. On August 1 and 2, as a further example, plant removals were very little improved by preaeration and this was sharply reflected by settlimeter test patterns which were much alike before and after preaeration.

In the paired data plots where preaeration markedly improved settling, most of the advantage, sometimes all of it, was gained in the first 15 to 20 min of settling. If this is also true in plant scale, its implications for both design and operation are quite important.

Primary Removals

This section is devoted to a review of the primary removal results for the 1958 Ames plant runs. Typical suspended solids results from individual samples for a two-week period are plotted in Figure 5; composite BOD and suspended solids results for the corresponding period are summarized in Table IV. It is apparent that preaeration was of consistent benefit to primary settling.

In general terms, BOD removals were improved from a median level of 31 per cent by plain settling to 38 per cent by settling followed preaeration. Similarly, SS removals were raised from 62 per cent to 70 per cent with the aid of preaeration. At the Ames plant, neither the aeration equipment or arrangement nor the amount of air used appeared to have any significant effect on the results.

Similarly, the preaeration detention time, within the probable mean time limits of 35 to 50 min, also appeared to be without influence on the benefit of preaeration. Again within the moderate limits experienced, incoming raw sewage strength likewise seemed to have

no effect on the degree of improvement. In fact, the only factor exhibiting a correlation with preaeration benefit was the removal accomplished by plain primary settling alone. A trend is apparent (Figure 6), and one which is confirmed by prior laboratory and plant-scale results. Improvement by preaeration of roughly 10 percentage points is indicated over the poorer plain settling removals, to only 5 to 6 points improvement when plain settling was doing unusually well.

When plain settling is at its best, preaeration has less margin in which to produce results. Far more important is the implication that preaeration is of greatest benefit when for some reason plain settling is at a disadvantage—and when primary treatment especially and total plant performance are most in need of help.

In commenting on these results, Robins (21) makes the following observation from a background of experience at the Minneapolis-St. Paul Sanitary District:

> It is my opinion that many sewage particles which should ordinarily settle out in the settling tanks during the normal detention periods are prevented from so doing because of the buoyant effect of grease, oils, and fats adhering to the particles. Preaeration of such raw sewages is, in my opinion, an action whereby the air bubbles diffuse through the sewage flow causing the sewage particles to bounce against one another effecting: (1) release of some of the grease, oils, and fats adhering to the particles; (2) agglomeration of the sewage particles causing their improved settling in the sedimentation tanks. The grease, oils, and fats released float to the surface to be removed in the skimming operations.

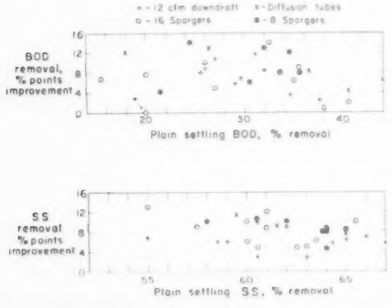

+ - 12 cfm downdraft x - Diffusion tubes
o - 16 Spargers • - 8 Spargers
BOD removal, % points improvement
Plain settling BOD, % removal
SS removal % points improvement
Plain settling SS, % removal

FIGURE 6.—Correlation of improvement due to preaeration with plain primary removals.

Plant Studies with Unequal Settling Time

Following the extensive runs described using all four primary clarifiers, another series of plant tests was made with one clarifier out of service. The flow was again accurately split, half passing directly to the north pair of primaries for approximately 2-hr settling; the other half was directed first to the south preaeration tank, then to one of the south primaries, providing only 1 hr settling.

In this direct operating comparison, preaeration and 1 hr settling outperformed 2 hr plain settling. In BOD removal, the difference was negligible, averaging a mere one percentage point. In suspended solids removal, however, the margin ranged from about two to five points and appeared fairly consistent throughout the day, except for the forenoon period of peak raw sewage strength and flow volume.

Studies at Other Iowa Plants

In August 1958, brief plant-scale studies were made at the Grinnell, Des Moines, and Cedar Rapids sewage treatment plants. All use preaeration as a first step in the treatment process. A major difference from the Ames plant is that in none of the three was it possible to split the flow for comparative operation with and without preaeration. Consequently, the only indication of benefit from preaeration at these plants was obtained through intensive laboratory use of the Oulman settlimeter. In addition, as full a background of supporting data on oxygen values, suspended solids, and BOD was gathered as time permitted. In December, an additional day was spent at both the Grinnell and Des Moines plants to gain a general idea of ORP values.

In each of the plants, laboratory work with the settlimeter indicated

definite improvement in settleability following preaeration. Whether or not this improvement was fully reflected in actual plant results is not known, although primary removals were very good in each case.

At Grinnell, preaeration increased the DO content of the raw sewage and maintained a positive DO level in the preaeration effluent throughout the day. At Cedar Rapids the reverse was true, with the preaeration effluent usually depleted or negative with respect to DO. At Des Moines, the raw sewage was strongly negative, and despite some improvement, left the preaeration tank still with a negative DO level. The grease separation and removal achieved at Des Moines was particularly impressive and was a key factor in successful operation of secondary treatment facilities.

Detailed operating and laboratory data for the studies at these plants are presented in the final project report (17).

Economic Evaluation

Engineering economy is defined succinctly by Grant (22) when he asks simply "Will it pay?" Somewhere in the development of every project or proposal this question must be injected if costs are of any concern.

Such a question involves first the outlining of possible alternatives. The next step is the analysis of prospective differences between these alternatives. Only the items that differ are relevant in such a comparison because the others cancel out. Finally, the physical differences are evaluated on a dollar basis. This answers the question "Will it pay?", on a strictly monetary basis. In practice, the choice between alternatives must also give weight to those factors, minor or major, which cannot be reduced to money terms.

As a basis of evaluation, preliminary plant designs were prepared with and without preaeration. Construction and operating costs were then estimated for the alternative designs.

Following conventional design standards, it was assumed that 35 per cent BOD removal would result from 2 hr plain settling. Where 45 min preaeration was provided, an additional 7 percentage points, or a total of 42 per cent primary BOD removal was assumed. The BOD load to the second stage, and its design capacity, were reduced accordingly for the preaeration alternative.

On this basis, the preaeration process in its role of challenger appears to be at a disadvantage both in first cost and in annual operating cost. This disadvantage is around 2 to 3 per cent in total annual cost. Therefore, based on conventional design criteria and giving weight to dollar differences only, preaeration apparently fails to measure up to the question, "Will it pay?"

Two other considerations are important here, however. The first is the demonstrated effect of preaeration on the early moments of settling. If 45 min preaeration followed by only 1 hr settling would be accepted as the equal of plain 2 hr settling, the preaeration alternative would be substantially on a par with conventional design in first cost.

The second consideration is the proved effectiveness of preaeration in separating grit from the raw sewage flow. Where preaeration could eliminate the need for a separate grit removal unit, an additional saving in both first and operating costs would be realized.

Conclusions

Preaeration proved to be of consistent benefit to primary settling. As a result of this study, the following conclusions are cited:

1. Intensive plant studies at Ames indicated an average improvement of 7 to 8 percentage points in both primary BOD and suspended solids removals following preaeration.

2. The degree of improvement or benefit seemed not to be affected by:

(*a*) the aeration method,
(*b*) the aeration rate, or
(*c*) the strength of the raw sewage.

3. The degree of improvement or benefit did show a correlation with the efficiency of plain settling. Preaeration was of most help when plain settling was least effective, and of least benefit when removals by plain settling were excellent.

4. The effect of preaeration on the early moments of settling appeared to be of prime importance. In laboratory settling tests, the full margin of improvement in the preaerated sample was often achieved in the first 10 or 15 min of settling.

5. In laboratory tests with 1-gal samples under ideal conditions, the combination of 30 min preaeration and ½ hr settling was found to outperform 2 or even 3 hr plain settling.

6. In brief plant-scale runs, the combination of 45 min preaeration and 1 hr settling consistently outperformed 2 hr plain settling, confirming the importance of preaeration on the early moments of settling.

7. At the Ames plant, an aeration rate of about 0.1 cu ft/gal was found necessary to match the short-term oxygen demand and thus maintain a constant DO level in the preaeration tank during relatively stable afternoon conditions.

8. An aeration rate of 0.1 cu ft/gal appeared to provide adequate turnover of the preaeration tank contents.

9. The oxygen transfer efficiencies achieved with conventional air diffusion equipment were fairly low, probably due largely to the absence of an active biological culture in the preaeration tank.

10. The preaeration process appeared to have no effect on the suspended solids content of the sewage passing through it, despite its influence on settling characteristics. If the BOD strength was affected, the amount was too slight to be observed in the BOD test.

11. Preaeration was found to provide a mild buffering action on peak loads reaching the plant. However, there was no evidence of a solids inventory established in the preaeration tank.

12. The effectiveness of preaeration in grit and grease removal was underscored by operating experiences at Ames and at the other Iowa plants visited. Provision for at least grit removal should be included in the design of preaeration facilities.

13. An alternative plant design including preaeration will permit an appropriate reduction in the secondary treatment facilities provided. However, if conventional design standards are followed strictly, this will result in a slight increase in both construction and operating costs, placing the preaeration alternative at a 2 to 3 per-cent disadvantage in total annual treatment cost. If primary settling capacity can be sharply reduced following preaeration, this cost disadvantage will be overcome. This cost comparison does not take into account any of the other benefits of preaeration, some tangible, some not.

14. Because of its striking effect on the early moments of settling, preaeration could provide economical relief to seriously overloaded plants by restoring primary settling to normal efficiency. The settlimeter would be of value in determining the effectiveness of preaeration on the waste being treated.

15. The applicability of the preaeration process can best be judged on its merits for each specific waste treatment problem. Construction and operating costs are nearly the same whether or not preaeration is provided. Therefore, the engineer's judgment is particularly important with respect to such secondary considerations as grit, grease, and treatability, and with respect to preaeration's effectiveness in coping with them.

Acknowledgment

This study was supported by research grant G-4504 from the U. S. Public Health Service, Division of Re-

search Grants and Fellowships, of the National Institutes of Health.

Acknowledgment is expressed to the city of Ames and particularly to John M. Carpenter, City Manager, for willingness to permit this rather lengthy plant-scale research project to be carried out at the municipal treatment plant. Special recognition is due Ralph W. Briley, Chief Operator, and Milo Sampson, Chief Mechanic, for suggestions and improvements to the preaeration equipment used; and to all other maintenance and operating personnel for faithful performance of sampling and other duties during the plant studies.

Appreciation is expressed to the Sutorbilt Corporation, Maywood, Calif., and to Zimmer and Francescon, their representatives in Moline, Ill., for the blower used in the plant-scale studies. The spargers used were furnished by Walker Process Equipment Inc., Aurora, Ill., and the diffusion tubes by General Filter Company, Ames, Iowa.

The authors gratefully acknowledge the help provided by graduate and undergraduate students who assisted in the project, particularly Jerry Edwards, Dennis Gere, Charles S. Oulman, and Donald K. Smith.

References

1. Roe, F. C., "Preaeration of Sewage by Air Diffusion." *Pub. Works*, **64**, 7, 15 (1933).
2. Rudolfs, W., and Gehm, H. W., "Chemical Coagulation of Sewage. V. Mixing of Chemicals and Flocculation." *Sewage Works Jour.*, **8**, 4, 547 (July 1936).
3. Rudolfs, W., and Gehm, H. W., "Chemical Coagulation of Sewage. VIII. Removal of Suspended Solids and BOD by Stirring and Diffusion of Gases." *Sewage Works Jour.*, **9**, 4, 579 (July 1937).
4. Fischer, A. J., and Hillman, A., "Improved Sewage Clarification by Preflocculation Without Chemicals." *Sewage Works Jour.*, **12**, 2, 280 (Mar. 1940).
5. Green, H. R., and McIntyre, J. C., "Flocculation Studies at Cedar Rapids, Iowa." *Water Works and Sewerage*, **84**, 383 (1937).
6. Hurley, J., "The Mechanical Flocculation of Sewage." *Surveyor* (Brit.), **51**, 15 (1942).
7. Popel, F., "Mechanical Flocculation of Suspended Solids in Municipal and Industrial Wastes." *Gesundh.-Ing.* (Germany), **66**, 213 (1943). *Sewage Works Jour.*, **17**, 2, 409 (Mar. 1945) [abs.].
8. Hurley, J., "Mechanical Flocculation in Sewage Purification." *Surveyor* (Brit.), **58**, 339 (1949).
9. Currie, F. S., "Preaeration, Grit Chambers, and Skimming Tanks." *Sewage Works Jour.*, **17**, 1, 46 (Jan. 1945).
10. Walker, J. D., "Preaeration Increases Sewage Treatability." *Sewage Works Jour.*, **20**, 1, 115 (Jan. 1948).
11. Lee, R. D., Wichita, Kans., private communication (1958).
12. Gunson, C. P., "Preaerated Raw Sludge Recirculation Increases Primary Sedimentation Efficiency at Denver." *Sewage Works Jour.*, **18**, 6, 1121 (Nov. 1946).
13. Mann, U. T., Syracuse, N. Y., private communication (1958).
14. Bargman, R. D., Betz, J. M., and Garber, W. F., "Aeration Requirements of a High Oxygen Demand Sewage." *Sewage and Industrial Wastes*, **29**, 7, 768 (July 1957).
15. Roe, F. C., "Preaeration and Air Flocculation." *Sewage and Industrial Wastes*, **23**, 2, 127 (Feb. 1951).
16. Heukelekian, H., and Wisely, W. H., "A Survey of Current Problems for Research." *Sewage and Industrial Wastes*, **26**, 9, 1155 (Sept. 1954).
17. Seidel, H. F., and Baumann, E. R., "The Effect of Preaeration on the Primary Treatment of Sewage." Final Rept., Proj. 332-S, Iowa Engr. Exp. Sta., Iowa State Univ. (1959).
18. Seidel, H. F., and Baumann, E. R., "The Effect of Preaeration on the Primary Treatment of Sewage." Bull. 187, Iowa Engr. Exp. Sta., Iowa State Univ. (1960).
19. Oulman, C. S., and Baumann, E. R., "A Colorimetric Method for Determining Dissolved Oxygen." *Sewage and Industrial Wastes*, **28**, 12, 1461 (Dec. 1956).
20. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York (1955).
21. Robins, M. L., Minneapolis-St. Paul Sanitary District, St. Paul, Minn., private communication (1959).
22. Grant, E. L., "Principles of Engineering Economy." 3rd Ed., Ronald Press Co., New York (1950).

VOLATILE ACIDS BY DIRECT TITRATION

Rosemarie DiLallo and Orris E. Albertson

The advent of high-rate digestion has necessitated use of laboratory tests which more completely describe the biochemical conditions within a digester. This is also true for conventional digesters approaching or exceeding design loading. Early detection of malfunction within a digester is dependent on routine tests in order to alleviate the situation before it becomes serious.

It is unfortunate that those tests of most value also happen to be the most difficult and time-consuming. Consequently, these data many times are not determined at all, and whatever value they may have had is lost. Often, other information of minor importance is collected due to the simplicity in the techniques of the analyses.

CO_2 content of the gas, pH, total alkalinity, and volatile acids are general chemical analyses run on a digester. The CO_2 content of the gas and volatile acids are infrequently determined, or not at all. In the case of the volatile acids, this is largely due to the time-consuming analysis. Of the four tests above, one or more may quickly reflect changes in biochemical environment which must be known to avert digester failures.

Digester Control Tests

An increase in the per cent CO_2 of the digester gas has been considered an indicator of impending failure in the anaerobic process. Changes can result from a periodic feeding schedule since the food material which is most easily reduced under anaerobic conditions usually produces digester gas of the highest CO_2 content. It is also true that an increase in CO_2 content may be related to a change in the chemical environment of a digester, but this is apparent only after the damage has been done. This is shown by the following:

$$NH_4HCO_3 + CH_3COOH \rightarrow CH_3COONH_4 + H_2CO_3 \quad (1)$$

$$H_2CO_3 \rightleftarrows CO_2 + H_2O \quad (2)$$

Here it is shown that an increase of 250 mg/l as acetic acid will destroy about 415 mg/l of bicarbonate alkalinity but the resulting acetate is equivalent to 320 to 350 mg/l total alkalinity. Thus, as acids increase, the bicarbonates are reduced and replaced by acetate alkalinity with the resulting increase in CO_2 content of the gas and only a slight decrease in alkalinity. The same equation shows that total alkalinity has little importance as a control parameter.

The pH, likewise, does not respond well to certain chemical changes in the digester. Although the pH is normally considered as a function of the bicarbonate alkalinity, it is more correct to say that it is a function of the ammonium nitrogen concentration. Thus, it is difficult to differentiate between pH and alkalinity, and they are best considered as one effect. The pH changes only slightly until the excess volatile acids exhaust the available ammonium nitrogen. Thereafter, organic acids are present as free acid and de-

Rosemarie DiLallo is Chemist at the New Rochelle Sewage Treatment Plant, New Rochelle, N. Y. Orris E. Albertson is Development Engineer for Dorr-Oliver Incorporated, Stamford, Conn. *The paper was presented at a New England Sewage and Industrial Wastes Association Meeting, Springfield, Mass.; May 26, 1960.*

press the pH accordingly. Generally, this point is equivalent to the bicarbonate alkalinity and some remedial steps should be taken long before it reaches this level. Normally, higher alkalinities allow greater shifts in volatile acids without affecting operation, since the pH is not affected. Sharp pH fluctuations can cause the digester to stop producing gas.

The value of the volatile acids tests for following the progress of the anaerobic digestion process has often been cited (1) (2). It is regarded by many as the only true indicator of the biochemical condition of a digester. It is not always so important to know what the true concentration of volatile acids is, as many digesters operate under equilibrium conditions with seemingly excessive concentrations of volatile acid. In these cases, it is important to detect a change in the volatile acids and the interval between observations should be a minimum.

Thus, the volatile acids could increase to a danger point, while the gas production and CO_2 content remain unchanged and the pH and total alkalinity may undergo an almost imperceptible change. Whether the digester fails by a decline in pH or an inhibitory concentration of acids will depend on the amount of alkalinity, but the prime cause is still the volatile acids.

Volatile Acids

The volatile acids in digesting sludges vary greatly both in concentration and the individual acid composition. These volatile acids are the end products of hydrolyzing the fats, proteins, and carbohydrates which make up the organic matter in the sludges. Although several of the low molecular weight volatile acids have been found in digesting sludges, acetic, propionic, and butyric have been reported (3) (4) (5) to constitute the majority of the acids present. Butyric acid has been shown by Buswell (5) to break down into two acetic acid molecules prior to being gasified, although it does not necessarily mean that it cannot be reduced directly to CO_2 and CH_4. Acetic acid is usually considered to be the predominant volatile acid present, comprising 50 to 90 per cent of the total. Recent work by Mueller *et al.* (3) shows the three principal acid groups to comprise about 98 per cent of the volatile acids. More striking is the change in the proportion of acids resulting from an increased loading. This change in acid composition was accompanied by an increase in acid concentration. As the volatile solids loading was increased from 0.05 to 0.135 lb/day/cu ft, the per cent acetic acid declined from 68.9 to 47.3, while propionic and butyric increased from 23.0 and 4.5 to 32.5 and 19.7 per cent, respectively.

Present Methods of Analysis

There are three principal methods to determine volatile acids and of these only one is adaptable for use in sludge digestion control. This method also happens to be the most inaccurate, although this is not considered an important failing since little additional benefit can be derived from knowing the exact concentration of volatile acids.

Heukelekian and Kaplovsky (6) proposed certain refinements for a steam distillation method which will recover 92 to 98 per cent of the volatile acids present. This method has been added to "Standard Methods" (7). However, in addition to the extensive apparatus that this test requires, about four hours are required to prepare the sample and complete the analysis. This method may be employed for research type of work, but is not very adaptable to daily control tests.

Chromatography (8) is a newer method which may be employed to determine total volatile acids, and also has the advantage of identifying the individual acid components and their concentrations. This is accomplished by eluting agents forcing the organic

acids to pass through a column in which they are selectively adsorbed and separated into bands of almost pure substances. Accuracy by this analysis, where no interfering substance is present, should be 95 per cent or higher.

The straight distillation method (7) is the procedure usually employed at most sewage treatment plants if the volatile acids are determined. The distillation may recover 68 to 85 per cent of the acids present, depending on the composition of the acids. This method is highly dependent on laboratory techniques to obtain reproducible results. Sludge solids should be removed from the sample, otherwise acid hydrolysis may occur. This procedure usually takes over an hour to complete, which includes preparing the sample.

Objective

The concern of this laboratory investigation was to establish a rapid, yet reasonably accurate method of determining the volatile acids in digesting sludges and also in raw sludges. It was desirable to use only that equipment normally found in a treatment plant laboratory and to employ such techniques which are common to other determinations required for plant control.

The laboratory equipment included pH meter, 2 50-ml and 1 10-ml burettes and titration stand, an adjustable hot plate, a laboratory centrifuge (optional), and a magnetic mixer (optional). A 4-place standard Kjeldahl apparatus was used for estimating the volatile acids present by the "short" distillation method.

Theory

The titration of digested sludge by acid to pH 4.0 is the method by which the alkalinity is determined (considered total alkalinity). Normally, the

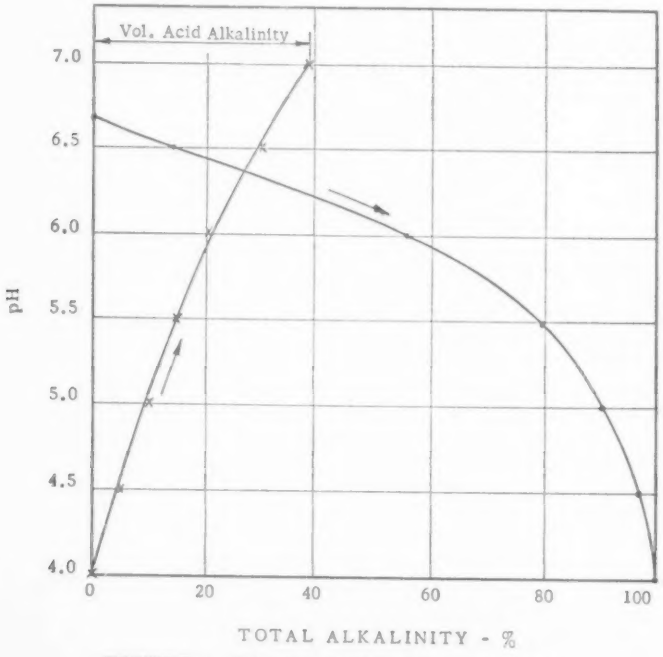


FIGURE 1.—Titration of volatile acid alkalinity.

majority of this value is bicarbonate alkalinity in the form of ammonium bicarbonate. However, the volatile acids, since they are found as acetates, propionates, etc., will also be titrated as alkalinity. Other ions, such as phosphates, will contribute to the total alkalinity, but their concentrations are quite small when compared to the bicarbonate and volatile acids. This phosphate alkalinity is denoted as base alkalinity since it does not change unless a big change in the raw feed sludge characteristics occurs.

The reduction of the pH to 3.3 will destroy the bicarbonate ion and boiling the sample removes all of the carbonic acid and CO_2 remaining in solution. The back titration from pH 4.0 to 7.0 will include the organic acids and the other minor ions present (base alkalinity). The conversion factor for determining the volatile acids present from the the acid alkalinity depends on the proportion of the acid which is titrated between pH 4.0 and 7.0. The equilibrium pH of organic acids is lower than 4.0, but this varies with the concentration of acids. Figure 1 is a graphical example of how this dual titration makes it possible to separate the volatile acids alkalinity from the total alkalinity.

Therefore, the back titration must reflect directly any change in the volatile acid concentration since it can be assumed that the digester is in solids equilibrium. That is, the average per cent total solids in the raw sludge does not vary greatly month to month, otherwise this would directly reflect in a change in total alkalinity. The result of doubling the total alkalinity (in effect, twice the feed solids) will also double the base alkalinity (minor ions), but will have little effect on the measurement of the volatile acid alkalinity. The following formulas show the steps involved:

1. Titration from initial pH to 4.0 (total alkalinity)

$$2NH_4HCO_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4 + H_2O + H_2CO_3 \text{ (bicarbonate)} \ldots (3)$$

$$2CH_3COO \cdot NH_4 + H_2SO_4 \rightarrow (NH_4)_2SO_4 + 2CH_3COOH \text{ (volatile acids)} \ldots (4)$$

$$2(NH_4)H_2PO_4 + H_2SO_4 \rightarrow (NH_4)_2SO_4 + 2H_3PO_4 \text{ (base phosphates)} \ldots . (5)$$

2. Boiling 3 min at pH 3.3 to 3.5 (remove carbonic acid)

$$H_2CO_3 \rightarrow CO_2 + H_2O \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)$$

3. Back titration from pH 4.0 to 7.0 (volatile acid alkalinity + base alkalinity)

$$(NH_4)_2SO_4 + 2CH_3COOH + 2NaOH \rightarrow 2CH_3COO \cdot NH_4 + Na_2SO_4 + 2H_2O \ldots (6)$$

$$(NH_4)_2SO_4 + 2H_3PO_4 + 2NaOH \rightarrow 2(NH_4)H_2PO_4 + Na_2SO_4 + 2H_2O \ldots . (7)$$

The principal positive ion present in sludge digestion is ammonium, although sodium, potassium, calcium, and others are present. Therefore, the salts formed in the equations above are considered as ammonium compounds, except those added while titrating.

Procedures

The digested primary sludges used in these experiments were obtained from sewage treatment plants at New Rochelle, N. Y. and Greenwich, Conn. The pH and alkalinity were 6.9 and 1,200 mg/l, and 7.0 and 2,000 mg/l, respectively. This would be a normal range of pH and alkalinity for a digested sludge where thickening was not practiced.

Increasing concentrations of volatile acids in the digesting sludge were prepared by overloading the sludge with raw sludge or adding prepared solutions of pure volatile acids. These

TABLE I.—Recovery of Pure Organic Acids by Distillation

Concentration of Acids Present (mg/l)	Avg Recovery of Acids (per cent)*		
	Acetic	Propionic	Butyric
300	65	84	100
—	60–30–10†	50–20–30†	50–10–40†
300	89	88	92
600	77	81	84
1,200	79	79	87
—	74.2‡	79.3‡	80.9‡

* As acetic acid.

† Blend of acetic, propionic, and butyric acid by per cent.

‡ Calculated recovery of 300 mg/l of respective acid blends.

solutions contained acetic, propionic, and butyric acid which had been neutralized with concentrated ammonium hydroxide. Three different stock solutions were used which contained 60, 30, and 10; 50, 20, and 30; and 50, 10, and 40 per cent, respectively, of acetic, propionic, and butyric acid when reported as acetic acid. That is, the individual 1.0 N acid solutions were mixed by volume to the above percentages.

Samples were prepared by settling the sludge and decanting the lighter fraction. Then, sufficient sample was centrifuged 5 min to obtain 4 50-ml aliquots. Centrifuging is not absolutely necessary since hydrolysis of organic matter cannot occur. Duplicate analyses were run for volatile acids by the tentative straight distillation method and by the titration method proposed in this paper.

The proposed phosphoric acid method (9) was tried with little success. The values recorded were almost invariably quite low and were inconsistent. Titration of the distillate by 25-ml fractions showed that a large portion of the acids recovered were found in the last fraction and seemingly contributed to most of the variance found. Several methods including those presented for removal of solids were tried, but this had little effect on the results. It was hoped that this test could be used for comparison of results.

The total alkalinity was determined by titrating with standard acid to pH 4.0, this amount noted, and the pH lowered to 3.3. The sample was then boiled lightly for 3 min, cooled, back titrated, and the amount of titrant noted from pH 4.0 to 7.0. All samples were run in duplicate and any singular value reported represents an average.

Results

The volatile acids on the sludge samples were determined by the straight distillation method and all calculations are based on 70-per cent recovery of the organic acids, although recoveries can vary greatly from this. In Table I are shown the recovery of organic acids of different known compositions and concentrations. Calculating the expected recovery of the mixtures from the distillation of the individual acids produced results much lower than those found. The acids in these distillations were not neutralized. The lower concentrations of acids produced higher recoveries. Also, higher recoveries were found as the butyric acid content increased, as was expected. Statistical analysis of the data indicated that the concentration had more effect than composition on the recovery of the acids.

Electrometric titration of the three

TABLE II.—Effect of Boiling Period

Time (min)	Volatile Acid Alkalinity (mg/l)		
	Sample A	Sample B	Sample C
0	1,295	—	—
¼	635	—	—
½	315	—	—
1	187	—	—
2	115	360	—
3	—	—	180
4	110	340	—
6	—	—	175
9	—	330	180

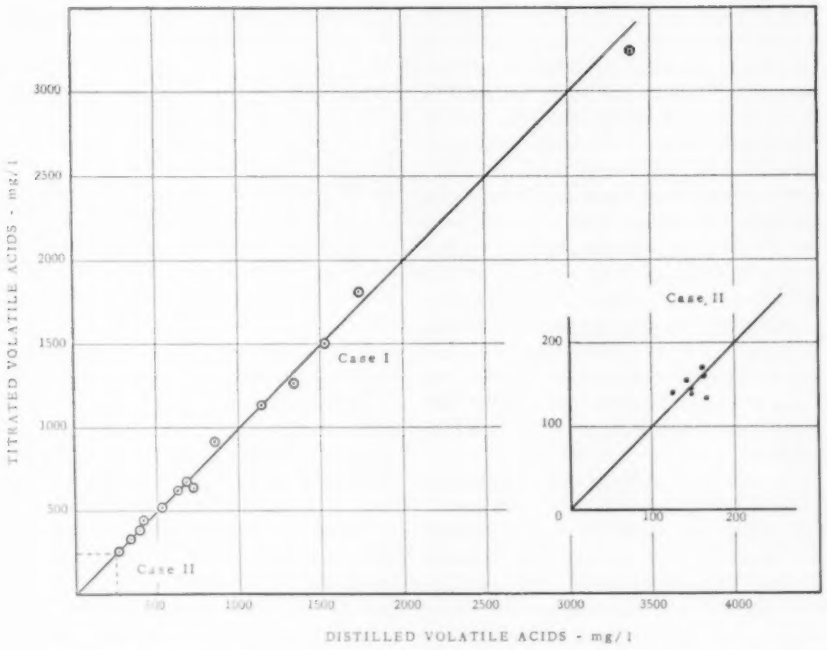


FIGURE 2.—Comparison of distillation and titration methods of determining volatile acids.

principal organic acids shows that their titration curves are identical when the same concentration of acids, as acetic acid, is used.

When the pH of the sample was lowered to the 3.3 to 3.5 range and boiled, it was necessary to establish the time required to boil off the CO_2 without losing volatile acids. In Table II, Samples A, B, and C are sludge samples, and the volatile acid alkalinity is determined after the specified boiling period. There is very little change in the acid alkalinity after 2 min, and seemingly it can be boiled lightly for 9 min without excessive losses. From these results, the 3-min boiling period was selected. Some of the pure acid mixtures were boiled 3 min to determine if any volatile acids were being lost. Oddly enough, ammonium neutralization of the volatile acids somehow reduced losses by boiling. In a sludge sample they are normally neutralized in this manner. Otherwise, the losses will be proportional to the butyric acid present. When the butyric acid content increased from 10 to 40 per cent, the loss increased from 2.9 to 10.8 per cent or 1:3.7.

Comparison was made of the two methods of determining volatile acids when 70 per cent recovery by distillation is assumed, and deviations are calculated about this value. The true concentration of acids was unknown. The data were divided into two cases, above and below 250 mg/l acids. Therefore, if the titration of the acid alkalinity was 180 mg/l or less, that value was reported (Case 2). Above this figure a factor of 1.50 was used to convert the acid alkalinity to volatile acids as acetic acids (Figure 2).

The standard deviation is only 4.07 for greater than 250 mg/l acetic acid and 10.0 for less than 250 mg/l acetic acid.

To establish whether the titration was reporting the true concentration of volatile acids, pure acid mixtures were added in known quantities to centrifuged samples prior to analysis by distillation and by the proposed titration method. It was found that the titration method was more accurate. The standard deviation was 6.5 compared to 11.2 for the distillation determination. In Figure 3, a portion of the data is graphed. This shows the relationship of the volatile acids distilled and calculated to that amount present. An estimated concentration of acids must be used since the base level of 370 mg/l was determined by triplicate distillation.

In order to determine the reproducibility of the analytical method, several duplicate tests for volatile acids by distillation and by the titration method were compared. The distillation method had an average deviation of 4.15 per cent and a standard deviation of 5.23, while the corresponding data for titration method were 2.48 and 3.30, respectively.

TABLE III.—Effect of Acid Concentration on Titration Results

Volatile Acids (mg/l)	Per Cent Recovery at pH 4.0 to 7.0	pH for 80 Per Cent Recovery	Equilibrium pH of Acid Concentration
100	80.8	4.03	3.7
300	81.6	4.05	3.6
600	80.0	4.00	3.4
1,200	77.2	3.94	3.2
1,800	76.9	3.92	3.1
3,600	77.8	3.93	2.9

All of the preceding calculations for estimating volatile acids from the acid alkalinity were based on the premise that 80 per cent of the organic acid titration is between pH 4.0 and 7.0. This is not true for all concentrations as shown in Table III. However, it is not sufficiently different to warrant complicating the factor used for com-

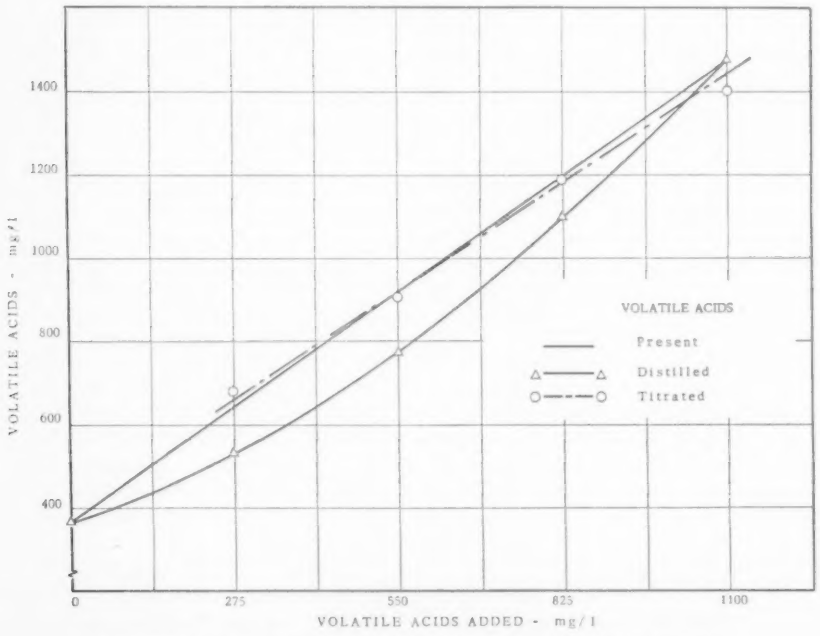


FIGURE 3.—Titration versus distillation for volatile acids analysis.

puting acid concentration, other than the consideration of acids above and below 250 mg/l as acetic, as previously noted.

Discussion

It is not known why recoveries on pure acid mixtures are so high (80 to 90 per cent instead of 70 per cent). However, there appears to be some difference when sludge liquor is distilled since apparent recoveries were as low as 58 per cent, and increased to 70 per cent when the acids reached almost 1,500 mg/l. There are many factors which affect the distillation recoveries. The type of apparatus, composition of the acids, distillation rate, and amount distilled are all known to affect the analysis. It appears that the concentration of volatile acids may alter recoveries, also. However, the statistical analysis of duplicate samples which were carefully distilled according to "Standard Methods" revealed that the standard deviation within the technique was still large. This was true even when the above factors were neutralized by comparison of the duplicate samples. The comparison of the distillation method to a good estimate of the volatile acids resulted in a standard deviation more than double that within the technique. It is probable that about 32 per cent of the distillation results will be 11.2 per cent or one standard deviation in error. From the same samples the proposed method had a standard deviation of 6.5 per cent of which only 3.3 per cent was due to variances in duplicate samples.

The proposed method titrates the volatile acids directly and is not influenced by the composition or the concentration of the volatile acids present. There was a small loss of volatile acids when pure acid mixtures were boiled the prescribed three minutes, but this is reduced greatly when ammonium nitrogen is present. Assuming that reasonable care is maintained in the boiling step, the accuracy is dependent on the precision of the electrometric titration from pH 4.0 to 7.0. The scale on the pH meter was 0.2 to 0.3 pH units off if buffered at 4.0 and used at 7.0. Therefore, the true reading was probably 6.7 or 6.8. Had the pH scale been linear, about 85 per cent would have been titrated instead of the 80 per cent which is reported. Most pH meters are not linear in this range.

When low concentrations of volatile acids are encountered, it is necessary to adjust the factor used to calculate the volatile acids from the acid titration. This is mainly due to base alkalinity (phosphates) being a much higher percentage of the acid titration. Rather than to set up a variable scale for calculating volatile acids when the acid alkalinity is less than 180 mg/l (as $CaCO_3$), the factor was decreased from 1.50 to 1.00. This appears satisfactory since there generally is not any problem of maintaining satisfactory digestion when the volatile acids fall below 250 mg/l as acetic acid.

It is believed that this method with some modification, such as determining the phosphates present, could be used to predict volatile acids concentrations with the accuracy of the steam distillation method. With this innovation, the proposed test could be used to quickly determine volatile acids in research projects. Too many times the volatile acid test has been omitted or used sparingly, when more complete data may have proved invaluable.

This work is planned to continue with the hope that at some later time a more accurate test will be established for the lower volatile acid ranges.

Summary and Conclusions

A discussion of the titration characteristics of the volatile acids indicates that after removal of the bicarbonate ion, the volatile acids can be titrated directly, although the titration would be increased slightly by minor concen-

trations of other ions. From these conclusions, a simple method of determining volatile acids requiring about 10 min to complete is proposed.

Numerous sludge samples and pure acid mixtures were analyzed by the straight distillation method, and a titration method was proposed. The data collected were analyzed to determine variation within duplicate samples and between the two methods. Also, variation between the two methods and a known concentration of acids was established. This comparison was extended over a wide range of volatile acids.

The comparison of the two methods showed the titration method to be much more consistent and accurate for acid concentrations over 250 mg/l while some adjustment was required for acids lower than this level. Many of the variables that affect the volatile acid distillation are not present or do not affect the measurement of volatile acid alkalinity. The titration analysis will detect any change in acids, whereas the distillation method may not reveal this change if the composition of acids was altered and different recoveries at various concentrations occurred.

The proposed test will provide the plant chemist with a rapid method of determining volatile acids in raw and digested sludges while still maintaining or probably improving his present accuracy. This test uses only that lab equipment normally used for other standard plant control tests.

APPENDIX—PROCEDURE

1. Buffer the pH meter at 7.0 and check pH before treatment of sample to remove the solids. Filtration is not necessary. Decanting or centrifuging sample is satisfactory. Do not add any coagulant aids.

2. Titrate 50 ml of the sample in a 100-ml beaker to pH 4.0 with the appropriate strength sulfuric acid (depends on alkalinity), note acid used, and continue to pH 3.5 to 3.3. A magnetic mixer is extremely useful for this titration.

3. Carefully buffer pH meter at 4.00 while lightly boiling the sample a minimum of 3 min. Cool in cold water bath to original temperature.

4. Titrate sample with standard 0.050 $\underline{N}$ sodium hydroxide up to pH 4.00, and note burette reading, and complete the titration at pH 7.0. (If this titration consistently takes more than 10 ml of the standard hydroxide, use 0.100 $\underline{N}$ NaOH.)

5. Calculate volatile acid alkalinity (alkalinity between pH 4.0 and 7.0).

$$\text{Volatile acid alkalinity} = \frac{\text{ml } 0.050\ \underline{N}\ \text{NaOH} \times 2{,}500}{\text{ml sample}}$$

For a 50-ml sample the volatile acid alkalinity = 50 × ml 0.050 $\underline{N}$ NaOH, or 100 × ml 0.100 $\underline{N}$ NaOH.

6. Calculate volatile acids.

Case 1. > 180 mg/l volatile acid alkalinity
Volatile acids = volatile acid alkalinity × 1.50

Case 2. < 180 mg/l volatile acid alkalinity
Volatile acids = volatile acid alkalinity × 1.00

Steps 1 and 2 will give the analyst the pH and total alkalinity, two control tests normally run on digesters. The difference between the total and the volatile acid alkalinity is bicarbonate alkalinity. The time required for steps 3 and 4 is about 10 min. Since the procedures are simple and quickly completed, duplicate samples are suggested. This permits the technician to detect any in-sample variation and to improve on the method. The average value is also a better estimate of the true concentration of volatile acids. Except for the optional equipment, the laboratory materials following are normally present in a treatment plant laboratory. Equipment and supplies required include: pH meter, 2 burettes and stand, 4.00 buffer solution, 7.00 buffer solution, standard acid and base, miscellaneous glassware, and adjustable hot plate. Optional equipment includes: centrifuge and magnetic mixer.

References

1. "Interpretation of Sewage Treatment Plant Tests—Panel Discussion." *Sewage and Industrial Wastes*, **31**, 1, 92 (Jan. 1959).
2. Buswell, A. M., "Important Considerations in Sludge Digestion. II. Microbiology and Theory of Anaerobic Digestion." *Sewage Works Jour.*, **19**, 1, 28 (Jan. 1947).
3. Mueller, L. E., Hindin, E., Lunsford, J. V., and Dunstan, G. H., "Some Characteristics of Anaerobic Sludge Digestion." *Sewage and Industrial Wastes*, **31**, 6, 669 (June 1959).
4. Mueller, H. F., Buswell, A. M., and Larson, T. E., "Chromatographic Determination of Volatile Acids." *Sewage and Industrial Wastes*, **28**, 3, 255 (Mar. 1956).
5. Buswell, A. M., and Hatfield, W. D., "Anaerobic Fermentation." Illinois State Water Survey, Bull. 32 (1939).
6. Heukelekian, H., and Kaplovsky, A. J., "Improved Method of Volatile Acid Recovery from Sewage Sludges." *Sewage Works Jour.*, **21**, 11, 974 (Nov. 1949).
7. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).
8. Neish, A. C., "Determination of Volatile Acids by Partition Chromatography." *Can. Jour. Research*, **B27**, 6, (1949).
9. Frook, J. E., "Volatile Acids by Direct Phosphoric Acid Distillation." *Sewage and Industrial Wastes*, **29**, 1, 18 (Jan. 1957).

RESEARCH OPPORTUNITIES

Research assistantships have been announced by two schools recently in the fields of sanitary engineering and environmental health.

1. **Northwestern University.** Research traineeships and fellowships are available for MS and PhD degree candidates with research interest in air pollution, biological engineering, water resources planning, operations research, and water and sewage treatment. Stipends are from $1,800 to $3,600 per year. Write: Dr. John A. Logan, Department of Civil Engineering, Northwestern Technological Institute, Evanston, Ill.

2. **Washington State University.** Research assistantships are available in water supply, wastewater treatment, and radiological problems leading toward an MS in Sanitary Engineering. A student may carry $\frac{2}{3}$ of a semester load in return for 20 hr of research. Write: G. H. Dunstan, Professor of Sanitary Engineering, Washington State University, Pullman, Wash.

TOXICITY OF CHROMIUM COMPOUNDS UNDER AEROBIC CONDITIONS

Robert S. Ingols and Robert H. Fetner

The study of toxicity of chromium compounds has been a matter of interest for many years, yet experiments have yielded a widely divergent set of conclusions concerning the magnitude of the toxicity. Studies by McKenzie *et al.* (1) with mice have indicated that no apparent lesions develop from ingesting chromates in the drinking water over many months. In a study of the BOD of sewage by manometric techniques, it has been shown by Ingols and Kirkpatrick (2) in long-term respiration studies that microorganisms show only a moderate effect from either chromic or chromate ions under aerobic conditions.

On the other hand, short-term aerobic studies by Ingols and Hilly (3) have shown that the respiration of activated sludge with a high food-to-sludge ratio was depressed by 70 per cent from small concentrations of chromate. Under anaerobic conditions, Meredith and Ingols (4) show that a small amount of chromate persisting in the digesting mixture can cause the organisms to remain dormant for a prolonged period.

Recently, Ingols and Fetner (5) have reported that moderate concentrations of chromate produce chromosomal aberrations in developing neuroblast cells. These chromosome aberrations are a radiomimetic effect and are considered to be important because of the possibility of long-term genetic effects.

By using a number of different approaches to the problem of toxicity, an attempt has been made to gain an understanding of the mechanism of the toxicity of the chromates which should aid in determining permissible concentrations in industrial wastes and potable water supplies.

Robert S. Ingols is Professor and Director of the School of Applied Biology at the Georgia Institute of Technology, Atlanta, Ga. Robert H. Fetner is Associate Professor in the same school.

Test Work

During digestion experiments (4), it was noted that mold mycelia appeared on the surface of those digesting mixtures which were unable to reduce all of the added chromate rapidly. This observation indicated that fungi might be more resistant to a given chromate concentration than bacteria. Accordingly, a series of petri dish plates were prepared with one milliliter of sewage in each plate together with a dextrose agar medium. Varying amounts of sodium chromate had been added to the agar before it was poured. Figure 1 shows the results obtained at the concentration of 500 mg/l. In this Figure mold mycelium can be seen but no bacteria. Chromate in the concentration of 500 mg/l prevented the growth of the bacteria to an extent that they did not compete for the food and space in the agar plate. Molds, however, are sufficiently resistant to the chromate at this concentration of 500 mg/l that they can develop. The molds do not develop rapidly, but they do develop in a normal, or an apparently typical manner. This particular observation was important in many ways. This technique should permit bacteriologists or mycologists to make the separation of a mixed culture of molds and bacteria and this should be a convenient, direct, inexpensive technique for evalu-

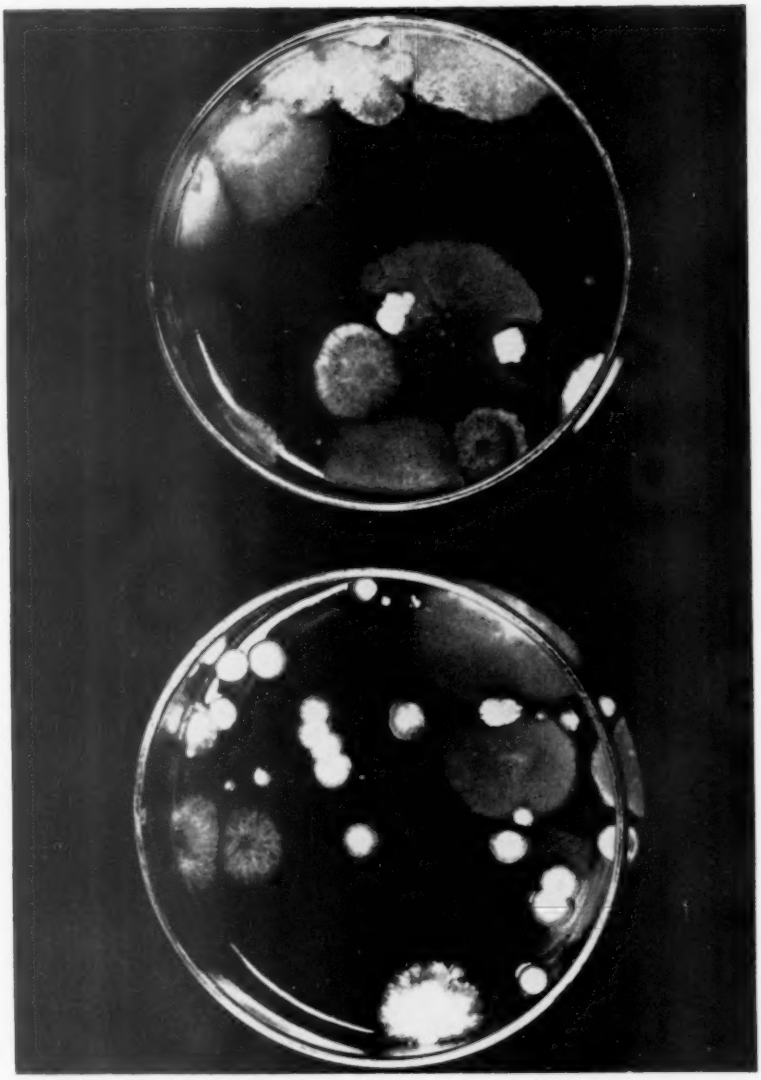


FIGURE 1.—Molds grown from 1.0 ml of sewage on dextrose agar plus 500 mg/l sodium chromate.

ating the number of molds in the presence of bacteria.

In aerobic studies (3) a mixed culture (a culture simulating activated sludge) was used for evaluating the toxicity of chromates. In these studies, it was noted that a sludge having a predominance of *Sphaerotilus*, or one having a predominance of *zoogloeal* masses gave rather different responses to the same concentration of chromate. When a sludge was dosed with chromate at each feeding to evaluate the degree of acclimatization, the sludge

became very bulky from filamentous growths. Because of the different sludge responses, different toxicities, and the different response of molds and bacteria at 500 mg/l chromate in agar, it was considered important to use pure cultures to evaluate the effect of chromate on respiration and to count the organisms surviving the respiration study period at various concentrations of chromate.

Therefore, an experiment was set up in which suspensions of *E. coli* were used in pure culture for measuring both the quantity of carbon dioxide generated during a 6-hr aeration period and the

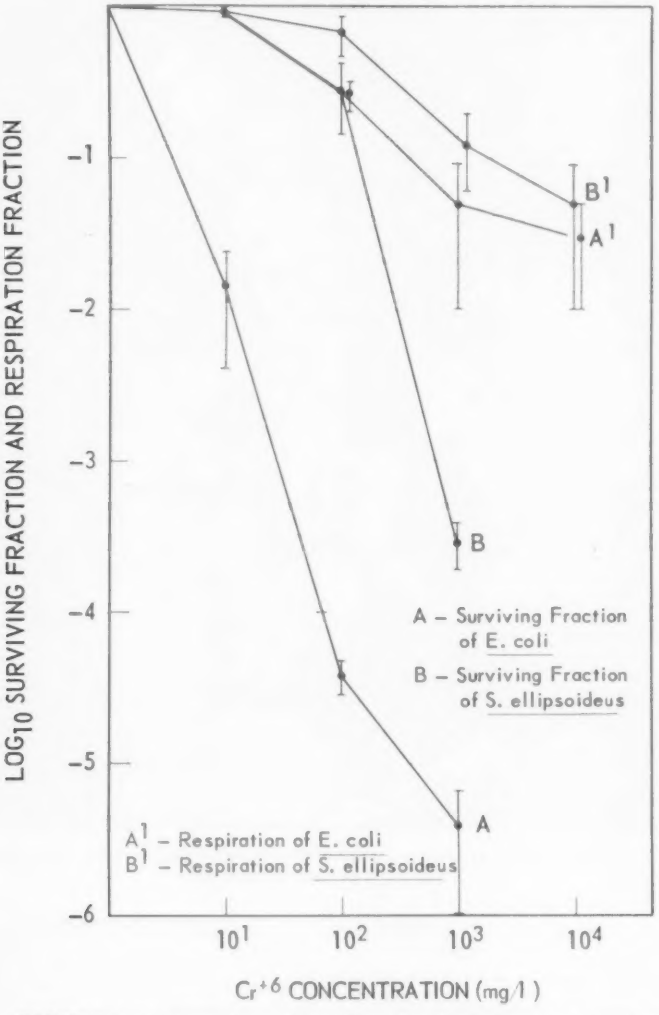


FIGURE 2.—A comparison of the effect of sodium chromate at various concentrations on the ability of two organisms, *E. coli* and *S. ellipsoideus*, to respire for a 6-hr period and the number of organisms which will grow on nutrient agar.

number of viable organisms which could be plated on nutrient agar after the respiration study. Hourly carbon dioxide production values were obtained for 6 hr to evaluate both the nature as well as the extent of the toxicity from a given chromate concentration. No attempt was made to remove the chromate from the bacterial suspension before the serial dilution on nutrient agar. *E. coli* was chosen as the bacterium to be studied because it would produce carbon dioxide under the aerobic conditions of the test equipment. The results shown in Figure 2 indicate that at a chromate concentration of 10 mg/l there was practically no effect on the respiration of the *E. coli*, yet it was possible to count only 1 per cent of the organisms as colony-producing survivors on nutrient agar following the 6-hr respiration period and contact with a chromate concentration of 10 mg/l.

When a similar experiment was repeated using yeast cells, *Saccharomyces ellipsoideus*, at a chromate concentration of 10 mg/l, there was no effect on respiration and approximately 99 per cent of the yeast were recovered as colony-producing viable organisms. The bacteria are much less able to produce visible colonies on nutrient agar than the yeast. However, the bacteria and yeast are not particularly different in the ability to respire (as measured by carbon dioxide production), except that in the chromate concentration of 100 mg/l a small but distinct difference in the respiration responses did occur.

Further studies comparing respiration with surviving organisms were repeated with the protozoa *Tetrahymena pyriformia*. The results are similar to those with the yeast. From an analysis of the work done by Catlin (6) with ferrous ions in producing micro-colonies with bacteria, it is reasonable to assume that the differences in response between the bacteria and the yeast may be the result of the fact that the yeast have a diploid number of chromosomes, while the bacteria have only a haploid set of chromosomes. Similarity in the responses of the protozoa and yeast resides in the fact that the protozoans also have multiple sets of chromosomes.

When similar studies of respiration versus colony-producing organisms from the respiring suspension were made with the trivalent chromic ion instead of the hexavalent chromate ion, an excellent correlation was observed between respiration and surviving organisms with all three of the organisms tested. This suggests, at least under the conditions of the experiment, the chromic ion has no apparent effect on genetic material in the living cells.

Discussion

The findings reported by Meredith and Ingols (4) which indicate a generally greater toxicity of the chromate ion over the chromic ion for anaerobic conditions were expected from studies of the literature. But the finding in this paper of a greater toxicity of chromate ions over chromic ions under aerobic conditions was not expected. The differences in earlier reported results and those given here are apparently a result of different techniques used in evaluating toxicity. In most earlier studies, observations were made after five days of continuous incubation. In this work it was found that differences in rates of respiration may occur for only limited periods of time. Ingols and Hilly (3) reported conflicting observations but were unable to account for the conflicts.

Ingols and Hilly (3) show that respiration rates during the third hour at a low food-to-sludge ratio may show a high factor of toxicity, while during the sixth hour there may be apparent stimulation due to the chromate. The stimulation is caused by the fact that the chromate has interfered enough with the respiration during the early hours of incubation so that there is a higher food concentration in the mix-

ture with chromate during the sixth hour than there is in the control, the mixture without chromate. The chromate does not generally interfere with low rates of respiration such as occur with the feeding of a pure sugar where new protoplasm does not develop. When new protoplasm can develop the apparent interference with respiration can become very severe (70 per cent at high food-to-sludge ratios).

The variation of toxicity with the stage of respiration and nutrition raises a problem of evaluating the quantity of chromates that can be tolerated in an industrial waste. What time period should be used or considered in arriving at reasonable limits for controlling the quantity of an industrial waste containing chromate to be added to a sewage treatment plant? Should only hourly rates be considered or should a total respiration be considered after 3, 6, or possibly 24 hr? With different temperatures giving different rates of respiration in the control and different periods of a high rate of respiration in the control when reproduction does take place, the choice of a rational basis for evaluating toxicity becomes more difficult.

Where the control of potable water is involved, the conclusion of Ingols and Fetner (5) seems reasonable; that is, the lowest possible quantity of chromate which can be attained is the only safe quantity of chromate for human consumption. This is true because it has been shown that chromate is radiomimetic and is involved in damage to genetic structures. Therefore, the toxicity of chromates or chromium compounds takes on an entirely different problem in potable water than it does in the treatment of a waste with activated sludge or in a mixed culture of microorganisms in sewage or industrial wastes. Where aerobic microorganisms must function, as in activated sludge, it is obvious that the presence of chromates will tend to cause a bulky sludge; that is, molds or *Sphaerotilus* will develop in preference to the zoogloeal masses in the presence of chromate. This development of a filamentous sludge was observed in attempts to obtain the comparison of toxicity with acclimated sludge over non-acclimated sludge.

Summary

The degree of depression of the respiration of an activated sludge by chromate during sewage treatment will depend on the amount of reproduction which would have occurred in the sludge within a short period of time. Thus, while the effect of chromium compounds on microorganisms is complex, the problem can be understood when it is realized that the chromates have an effect on the genetic expression. The chromic ions show a toxic effect on microorganisms, but the data do not indicate where the attack occurs.

References

1. McKenzie, R. D., Hoppert, C. H., and Byerrum, R. U., "Studies of Cadmium and Chromium Solubility and Toxicity." *Jour. Amer. Water Works Assn.*, **49**, 10, 1310 (Oct. 1957).
2. Ingols, R. S., and Kirkpatrick, E. S., "Study of Chromium Toxicity by Several Oxygen Demand Tests." *Anal. Chem.*, **24**, 1881 (1952).
3. Ingols, R. S., and Hilly, L. T., "Limiting Toxic Values." *Proc. Fifth Southern Municipal and Industrial Wastes Conf.*, 107 (1956).
4. Meredith, J. C., and Ingols, R. S., "The Effect of Potassium Chromate on Sludge Digestion." Presented at Chicago Conf. of Amer. Chem. Soc. (1958).
5. Ingols, R. S., and Fetner, R. H., "A Discussion of Toxic Pollutants in Potable Water." *Proc. 7th Southern Municipal and Industrial Wastes Conf.*, p. 29 (1958).
6. Catlin, B. W., "Response of *Escherichia coli* to Ferrous Ions. III. Application of a Method for Estimating Cellular Division to a Study of Recovery and Mutation." *Jour. Bact.*, **71**, 406 (1956).

TEMPERATURE AND FLUOROSIS IN RAINBOW TROUT

Joseph W. Angelovic, William F. Sigler, and John M. Neuhold

The prevalence of pollution of natural waters today makes it important to know the relation of fish to toxic amounts of the materials being introduced into the aquatic environment.

The addition of fluoride to domestic water supplies for prevention of dental caries has increased interest in the effects of fluoride on the aquatic environment. Fluorides have been studied extensively over the past 20 yr, but mostly concerning their effects on mammals. Fish have received minor attention in research.

Fluorides occur naturally in many waters, especially in the western United States. These waters generally contain low concentrations of fluoride except in some instances such as the Firehole and Madison Rivers in Yellowstone National Park, which contain from 1 to 14 mg/l and Walker and Pyramid Lakes in Nevada which contain up to 13 mg/l.

Fluorides also enter the aquatic environment by leaching from superphosphate fertilizers in the soil and from naturally occurring deposits of such minerals as fluorite, apatite, cryolite, and sedimentary phosphate rock. Other sources of fluoride are the waste products from such industries as metal refining plants, fertilizer plants, and ceramic plants.

Another identity which can be lethal in the aquatic environment is temperature. Normally temperature accentuates the effects of toxic substances in the aquatic environment. The purpose of this study was to investigate the effects of temperature on the toxicity of fluorides to rainbow trout as well as the effects of different temperature levels and varying fluoride concentrations on rainbow trout.

Very little work has been done on the toxicities of fluorides to fish. Lethal levels of sodium fluoride for goldfish were determined by Ellis (1) and indicated that 1,000 mg/l fluoride killed goldfish in 60 to 102 hr in hard water. In soft water at 1,000 mg/l the time to mortality ranged from 12 to 29 hr. In hard water at 100 mg/l he found no mortality in 4 days. Investigations by deRoos (2) attributed death of goldfish within 4 days to concentrations of 120 mg/l fluoride. Neuhold and Sigler (3) state that in water low in calcium and magnesium, the LC 50 * for rainbow trout falls between 2.7 and 4.7 mg/l fluoride, while the LC 50 for carp lies between 75 and 91 mg/l fluoride.

Ellis *et al.* (4) thought that sodium fluoride had no immediate severe adverse effects, since goldfish lived 10 days or longer in water containing 200 mg/l fluoride.

Normally the toxic effects of fluorides are observed only when high concentrations of the ion exist (5), but as stated by Neuhold and Sigler (3) in relation to fluorides and Powers (6) in relation to chlorides, the toxicities of these ions increase as temperature increases.

Powers (6) demonstrated that temperature modifies the effect of a given

Joseph W. Angelovic, is Research Assistant in the Department of Wildlife Management; William F. Sigler is Head and Professor of the Department of Wildlife Management; and John M. Neuhold is Assistant Professor of Wildlife Management; all are at Utah State University, Logan, Utah.

* Lethal concentration to 50 per cent of the fish.

concentration of a substance according to definite laws, and that the rise of one degree at high temperatures has a much greater effect than one degree rise at low temperatures. He postulates that the increased sensitivity at high temperatures might be because the fish has neared its upper lethal thermal level.

Materials and Methods

Two thermostatically controlled tanks were used as a water bath for 24 10-gal aquaria. Each aquarium held 30 l of tap water which was passed through a commercial water softener to remove excess calcium and magnesium. Fluoride was added to the aquaria as sodium fluoride.

The rainbow trout were thermally acclimated to the desired temperature for at least 48 hr. They were then introduced into the aquaria at the rate of 0.08 g of fish per square centimeter of surface area. All fish were selected from the same stock and were from 3 to 5 in. long and weighed between 15 and 25 g.

The trout were exposed to concentrations of 0, 2, 4, 7, 13, and 25 mg/l fluoride at temperatures of 45, 55, 65, and 75°F. The number of 8-hr time units to the deaths of the individual fish were recorded. The experiments were terminated at 240 hr.

Analyses of variances were run to determine the effects of high fluoride concentration and temperature on the time to the initial mortality, on the time to the final mortality, on the rate of mortality, and on the duration of the mortality period.

Probit analyses were run to determine the sensitivity and LC 50 of the rainbow trout to different concentrations of fluoride at varying temperatures. Sensitivities and LC 50's were estimated at the 95 per cent confidence level.

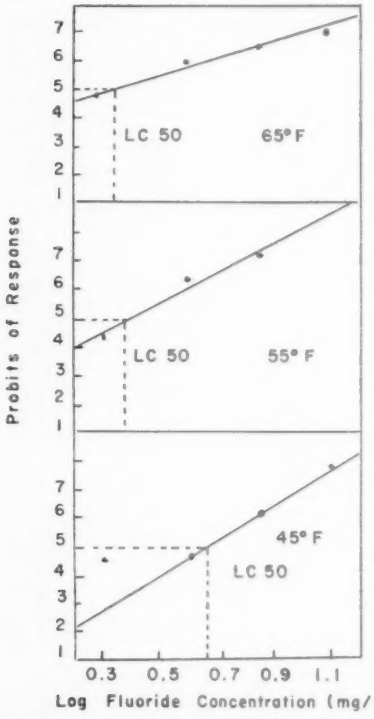


FIGURE 1.—The response of rainbow trout to the log of the fluoride concentration in 30–1 aquaria at various temperatures.

Results

Temperature-Concentration Relations

The result of the probit analyses show that temperature had an effect on both the LC 50 of rainbow trout and the sensitivity, which is defined as the change in the probits of response per unit change of fluoride concentration.

At 45°F, the LC 50 was estimated between 5.9 and 7.5 mg/l fluorides. At 55°F the LC 50 was between 2.6 and 6.0 mg/l fluorides and at 65°F the LC 50 was between 2.3 and 7.3 mg/l fluorides. Mortality was complete in so many concentrations at 75°F that it was impossible to establish an LC 50. There was a steady decrease of LC 50 with temperature increases.

The sensitivities of rainbow trout at 45, 55, and 65°F were between 3.94 and 8.36, 3.42 and 6.76, and 1.89 and

TABLE I.—Mean Values of the Number of 8-hr Time Periods to the Initial Mortality of Rainbow Trout at Varying Levels of Temperature and Fluoride Concentration

Temp.* (°F)	Fluoride Concentration* (mg/l)						Mean No. 8-hr Time Periods by Temperature
	0	2	4	7	13	25	
45	29.25	24.75	15.75	9.00	6.00	3.25	14.67
55	24.50	23.00	13.50	6.50	5.00	4.50	12.83
65	18.75	15.00	11.25	10.50	4.00	4.00	10.58
75	2.00	2.25	1.75	1.75	1.25	1.25	1.71
Mean No. 8-hr time periods by concentration	18.62	16.25	10.56	6.94	4.06	3.25	—

* Significant at the 99-per cent confidence level.

4.05 probits of response per unit of the log of fluoride concentration, respectively. The response of rainbow trout to a unit of the log of fluoride concentration decreased steadily with the temperature increase.

The relationship between the log of the fluoride concentration and the probit of response for the three temperatures is shown in Figure 1. At 45°F the curve is expressed by $Y = -0.05 + 6.15X$; at 55°F the curve is $Y = 2.02 + 5.09X$; and at 65 F it is $Y = 2.97 + 2.97X$.

Initial Mortality

The effects of concentration of fluorides, temperature of the medium, and their interaction on the time to the initial mortality of rainbow trout, were all significant at the 99 per cent level of confidence (Table I). The linear component of regression for concentration of fluoride was significant at the 99 per cent level of confidence. This indicates a linear relationship where there is a steady decrease in the time to initial mortality of rainbow trout with increased fluoride concentration. Temperature best fits a second degree polynomial. In the temperature curve, the time to initial mortality decreases as temperature increases. At the higher temperatures the decrease in time to initial mortality per unit increase of temperature becomes more rapid.

Seventy-five degrees appears to near the lethal limit of rainbow trout. This temperature, at all fluoride concentrations, showed the least time to initial mortality. At 45 and 55°F the greatest effect on the time to initial mortality of rainbow trout appeared between 2 and 4 mg/l fluorides. At 65°F, which seemed to be an optimum temperature for rainbow trout under the duress of fluorides, the greatest effect on the time to the initial mortality did not appear until the fluoride concentration was between 7 and 13 mg/l fluorides.

Final Mortality

Effects of temperature, concentration of fluoride, and their interaction, on the time to final mortality were all significant at the 99 per cent level of confidence (Table II). The components of regression for the concentrations showed a predominantly linear relationship. The time to final mortality decreased steadily with an increase in fluoride concentration. Temperature followed a cubic relationship with the time to final mortality. The time to final mortality decreased sharply as the temperature increased from 45 to 55°F. A slight decrease in the time to final mortality appeared between 55 and 65°F; the time to final mortality decreased rapidly as temperature increased from 65 to 75°F.

Seventy-five degrees again appears to be the lethal limit of rainbow trout,

TABLE II.—Mean Values of the Number of 8-hr Time Periods to the Final Mortality of Rainbow Trout at Varying Levels of Temperature and Fluoride Concentration

Temp.* (°F)	Fluoride Concentration* (mg/l)						Mean No. 8-hr Time Periods by Temperature
	0	2	4	7	13	25	
45	29.25	29.00	21.25	22.50	12.00	10.75	20.79
55	25.50	28.50	18.00	15.50	9.50	7.25	17.37
65	23.25	21.75	18.75	13.75	14.75	6.75	16.50
75	3.50	6.50	2.75	2.75	2.25	2.25	3.33
Mean No. 8-hr time periods by concentration	20.37	21.44	15.04	13.62	9.62	6.75	—

* Significant at the 99-per cent confidence level.

since at this temperature all fluoride concentrations seem to have the greatest effect on the time to final mortality. At 45 and 55°F the greatest effect on the time to final mortality appeared between 7 and 13 mg/l. Again, 65°F seems to be the optimum temperature for rainbow trout subjected to concentrations of fluorides. The greatest decrease in the time to final mortality falls between 13 and 25 mg/l fluorides.

Rate of Mortality

The analysis of variance shows the effects of temperature and concentration of fluoride on the rate of mortality are significant at the 99 per cent level of confidence (Table III). The interaction of temperature and fluoride concentration has no significant effect on the rate of mortality of rainbow trout. The effect of fluoride concentration tends to hold to a straight line relationship with the rate of mortality increasing with an increase in fluoride concentration. Temperature follows a quadratic relationship with the rate of mortality. There is a slight decrease in the rate of mortality from 45 to 55°F and then a steady increase in the rate of mortality with an increase in temperature.

Duration of Mortality

The analysis of variance shows that temperature has a greater effect on the duration of the mortality period (Table IV). Temperature is significant at the 99 per cent level of confidence. Concentration of fluoride also has a significant effect on the duration of the

TABLE III.—Mean Values of the Number of Rainbow Trout Dying Per 8-hr Time Period at Varying Levels of Temperature and Fluoride Concentration

Temp.* (°F)	Fluoride Concentration* (mg/l)						Mean No. Dying Per 8-hr by Temperature
	0	2	4	7	13	25	
45	0.25	0.04	0.59	0.43	0.85	0.61	0.46
55	0.50	0.17	0.61	0.46	0.92	1.13	0.63
65	0.33	0.65	0.25	0.56	0.72	1.02	0.59
75	1.25	1.01	1.25	2.42	3.17	2.71	1.97
Mean No. dying per 8-hr by concentration	0.58	0.47	0.67	0.97	1.41	1.37	—

* Significant at 99-per cent confidence level.

TABLE IV.—Mean Value of the Number of 8-hr Time Periods in Duration of the Mortality Period of Rainbow Trout at Varying Levels of Temperature and Fluoride Concentration

Temp.* (°F)	Fluoride Concentration† (mg/l)						Mean No. 8-hr Time Periods by Concentration
	0	2	4	7	13	25	
45	0.00	4.25	5.50	13.50	6.00	7.50	6.12
55	1.00	5.50	4.50	9.00	4.50	2.75	4.54
65	4.50	6.75	7.50	3.25	10.75	2.75	5.92
75	1.50	4.25	1.00	1.00	1.00	1.00	1.62
Mean No. 8-hr time periods by concentration	1.75	5.19	4.62	6.69	5.56	3.50	—

* Significant at 99-per cent confidence level.
† Significant at 95-per cent confidence level.

mortality period but only at the 95 per cent level of confidence. There is no significant effect from their interaction. The cubic component of regression is significant at the 95 per cent level of confidence for temperature. The duration of the mortality period decreases sharply up to 55°F. There is an increase in the duration of the mortality period up to 65°F and then a sharp decrease up to 75°F. The quadratic component of regression for concentration of fluoride is significant at the 99 per cent level of confidence. There is an initial increase of the duration of the mortality period with an increase in fluoride concentration. As the fluoride concentration continues to increase, the duration of the mortality period starts to decrease.

Discussion

This study was concerned with three major factors: (*a*) the toxic effects of fluoride concentrations on rainbow trout, (*b*) the effects of different temperature levels on rainbow trout, and (*c*) the effect of temperatures on the toxicity of fluoride concentrations.

Effects of Fluoride on Rainbow Trout

Concentrations of fluorides, which caused acute intoxication of rainbow trout, brought on symptoms very similar to those described by Neuhold and Sigler (3) and deRoos (2) in their studies of lethal doses of fluorides on fish. The general order of symptoms were an initial lethargy; then violent, aimless movements with a loss of equilibrium; and finally death in a state of partial or complete muscular paralysis.

Calcium and magnesium were kept at a low level during the experiment so these ions would not counteract the effect of the fluorides. Both of these ions tend to form stable, relatively unsoluble complexes with fluoride. Neuhold and Sigler (3) show that high concentrations of calcium in the medium at least tend to delay the symptoms expressed by a fish under fluoride intoxication. By elimination of high concentrations of calcium and magnesium, the sensitivity of the experiment is increased. Fluoride acts as an enzymatic poison especially on those enzymes needing divalent cations such as calcium and magnesium as activators.

It has been known for some time that the fluoride ion acts in a laboratory test device as an inhibitor of certain enzyme catalyzed reactions. Some of the enzymes sensitive to fluoride are phosphatases, enolase, adenosine triphosphate, phosphoglucomutase, succinic dehydrogenase, hexokinase, and pyruvic oxidase.

The over-all effect of fluoride con-

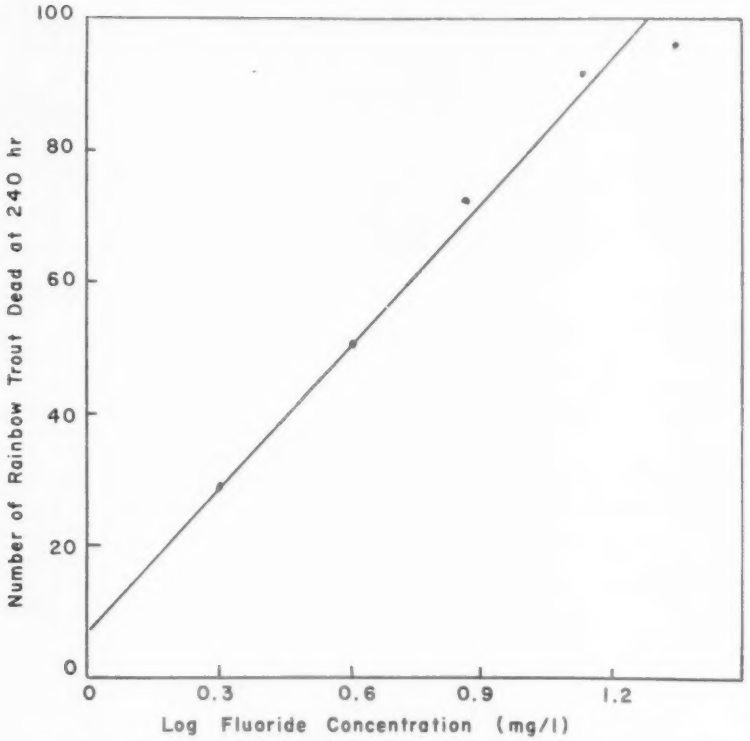


FIGURE 2.—The relationship of the log of the fluoride concentration to mortality. The curve represents the approximate linearity.

centration on the mortality of rainbow trout is a direct linear relationship in which an increase in fluoride concentration produces an increase in mortality (Figure 2).

The amount of the fluoride concentration has a significant effect on the time to initial mortality, time of final mortality, rate of mortality, and the duration of the mortality period. With an increase in fluoride concentration there is a steady decrease in the length of time to initial and final mortalities. An increase in fluoride concentration also causes a steady increase in the rate of mortality; more fish die per time period with each increase in fluoride. With an increase in fluoride the duration of the mortality period initially increases, and then as the fluoride concentration continues to increase the duration of the mortality period starts to decrease. This may be because the lower concentrations of fluoride are not actually lethal to the rainbow trout and may, at certain low concentrations, act as a deterrent to other causes of mortality such as bacterial or fungal infections. Actually the number of rainbow trout dying in the low concentrations was very small and could have been either natural mortality or some other factor such as a physiological stress due to space limitation. Since only one or two fish died in the low concentration, and those died at almost the same time, the short duration of the mortality period in the low fluoride concentrations is actually misleading. When the concentration of fluoride be-

comes high enough to be toxic, the duration of the mortality period decreases as the fluoride concentration increases.

Effects of Temperature on Rainbow Trout

In this study no lethal effects were attributable to temperature alone, except at the 75°F level. Here there was a high proportion of mortality even in the presence of no fluoride. This can only be taken as thermal death. The 75°F temperature just reaches the upper lethal limit as reported for rainbow trout. The lethal limit normally falls between 74 and 78°F. Rainbow trout which have been acclimated and then have their temperature raised at the rate of 1°F per hour do not reach the upper lethal level until about 80°F. The fact that the water used was low in calcium and magnesium may explain the slight lowering of the lethal limit. Halsband (7) was able to raise the lethal temperature of rainbow trout at least 2°C by increasing the calcium and magnesium content of the water. It may be that the removal of these ions lowered the upper lethal temperature.

In the relationship of temperature to mortality (Figure 3) there appears to be a plateau between 55 and 65°F; i.e., an increase in temperature did not bring about an increase in mortality. This curve is very similar to that of Job (8) where he found a similar plateau to exist in measuring the metabolic rates of fish. It usually occurs just above the preferred temperature of the species.

The analyses of variances show that

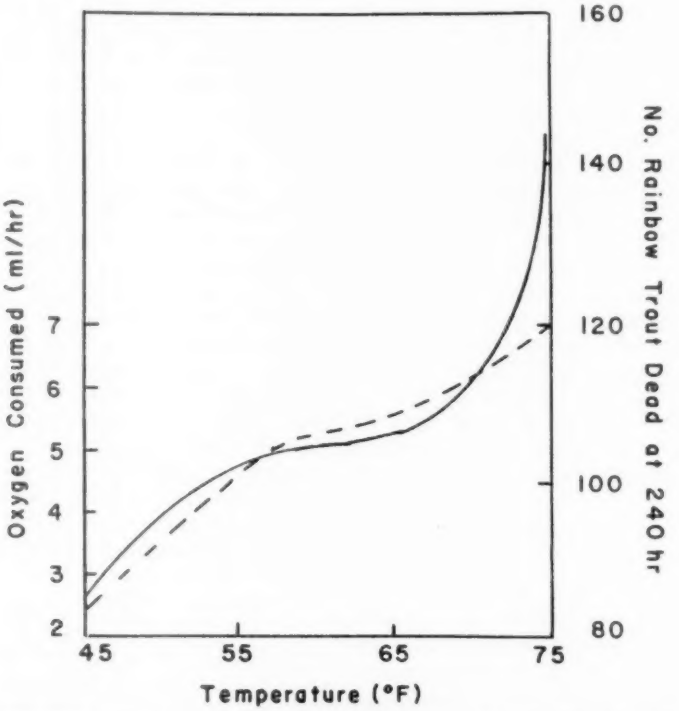


FIGURE 3.—Comparison of the temperature-mortality curve with that from Job (Ref. 8) for metabolism.

temperature has a significant effect on all the measured responses of rainbow trout. As temperature increases to 65°F, the time to initial mortality decreases gradually; but as it nears 75°F, the time to initial mortality decreases very rapidly. This can be attributed to the fact that 75°F appears to be the upper lethal limit, and therefore none of the rainbow trout should be able to exist very long at this level. The other measured responses—the time to final mortality, the rate of mortality, and the duration of mortality period—all show the result of nearing the lethal limit by the greatly increased response resulting from the rise in temperature from 65 to 75°F.

The results of all the measured responses coincide very well with the curve found in measuring the metabolic rate of rainbow trout (8). At 45°F it takes more time to incur both the initial and the final mortality of rainbow trout than at higher temperatures. The number of rainbow trout dying per time period is less at 45°F than at higher temperatures, and the duration of the mortality period is longest at 45°F. These effects are likely due to the decreased rate of metabolism.

In the range from 55 to 65°F there is a region in which the increase in temperature does not give an increased response. The times to initial and final mortalities and the rate of mortality are almost the same at both 55 and 65°F, giving the same type of plateau as found in the measurement of the metabolic rates of rainbow trout.

Effects of Temperature on the Toxicity of Fluoride

In an evaluation of the effect of temperature on the toxicity of fluorides, the fact that either factor by itself can be lethal must be considered.

The data show quite conclusively that increased temperatures cause an increase in the toxicity of the fluorides. It seems likely that this is caused by the increased rate of metabolism.

In this case the two lethal factors can be placed into two different categories: (*a*) controlling lethal factor and (*b*) limiting lethal factor. Fry (9) defines a controlling factor as "one which governs the metabolic rate by virtue of its operation within the metabolic chain."

In this case temperature falls into the former and fluoride into the latter.

That fluoride acts within the metabolic chain, specifically as an enzymatic poison, is shown by many authors. This being the case, the results obtained here were predictable. The increase in the metabolic rate would bring about a faster absorption of fluoride into the metabolic chain, causing a quicker poisoning of the enzyme system.

The actual mechanism by which the fluoride interrupts the metabolic processes remains a matter of speculation. It may inhibit by some unknown mechanism, or it may inhibit the synthesis of required coenzymes. Another means by which it may inhibit metabolism is by combining with the calcium and magnesium ions which in many instances are needed as cofactors by different enzymes.

In this part of the study, the relation of temperature to the rate of routine metabolism was the important aspect. Routine metabolism, or the metabolism under normal conditions, was the assumed condition of the experiment. The fact that an increase in temperature increases the rate of the basal metabolism of fishes has been well established. The routine metabolism of trout also increases with an increase in temperature.

The influence of temperature on the toxicity of fluorides is easily seen from the results of the probit analyses. The LC 50 of fluoride at 45°F is the highest. At 55 and 65°F the estimated LC 50's are almost the same. Mortality at 75°F was so high that no LC 50

could be determined. Assuming the slight differences between the estimated LC 50's at 55 and 65°F to be due to variation, the results showing an increased response to fluoride with an increase in temperature, except between 55 and 65°F, fit the routine metabolism curves of Job (8) very well. The plateau of the curve falls in the same region that Job found a plateau for metabolism in rainbow trout.

The sensitivity, measured as the probit of response per unit of the log of fluoride concentration, decreased as the temperature increased. At first this seems to disagree with all the other data. What happens in this case is at the higher fluoride concentrations all of the rainbow trout died at all temperatures. The lower concentrations of fluoride get an increased mortality with increased temperature, thereby lessening the slope of the line which is a measure of the sensitivity. This is explained by the fact that probit analyses do not take into consideration the time factor. If the data were analyzed at the time the last trout died in the high concentration, the number of deaths in the lower concentrations would all be lower and this would give an increased slope to the line. What actually happens is, in all concentrations, death takes place sooner with an increase in temperature.

Plotting temperatures against mortality for different concentrations of fluoride (Figure 4) demonstrates clearly the relationships involved. As

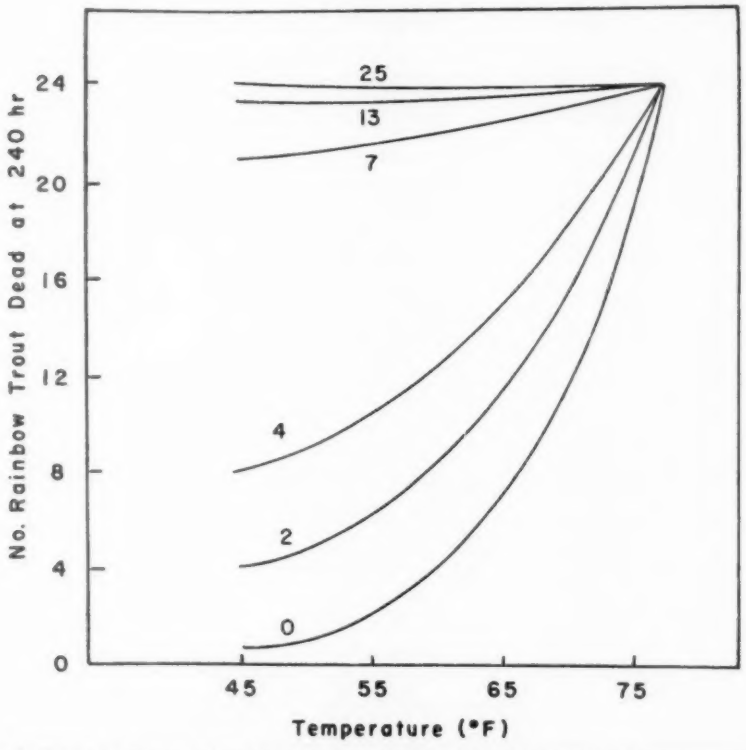


FIGURE 4.—The relationship at different levels of fluoride (mg/l) of temperature to the mortality of rainbow trout.

the fluoride concentration increases, the impact of temperature on the mortality becomes progressively less. The lower concentrations show a much greater response to temperature as it passes the optimum temperature range toward the upper lethal limit than do the higher concentrations.

The analyses of variances in the study show that the interaction of temperature and fluoride concentration has a significant effect on the time of initial and final mortalities. There is no significant effect demonstrated by their interaction on either the rate of mortality or the duration of the mortality period.

The table of means obtained from the times to initial mortalities (Table I) shows a definite interaction between fluoride concentration and temperature. While the relationship of fluoride concentration to initial mortality is a linear one, and the relation of temperature to initial mortality follows a second degree polynomial, the interaction of the two shows 75°F to have a lethal effect on rainbow trout at all concentrations. The greatest effect on the time to initial mortality takes place between 2 and 4 mg/l fluoride at 45 and 55°F, but 65°F seems to be an optimum temperature at which the increased fluoride concentrations do not affect the time to initial mortality until they reach 7 to 13 mg/l fluorides.

The table of means obtained from the times to final mortalities (Table II) shows again an interaction between fluoride concentrations and temperature. Here the relation of fluoride concentration to final mortality is linear, and the relation of temperature to final mortality follows a third degree polynomial. Again the interaction shows 75°F to be lethal at all concentrations and 65°F appears to be the optimum temperature for rainbow trout under varying fluoride concentrations. At 45 and 55°F the greatest effect on the time to final mortality takes place between 7 and 13 mg/l while at 65°F it takes place between 13 and 25 mg/l fluorides.

From these tables it seems that under the duress of fluorides the upper lethal temperature for rainbow trout is 75°F. It also seems 65°F is an optimum temperature for rainbow trout since they are able to survive for a longer period at this temperature in a given concentration of fluoride than at other temperatures tested.

It is evident from the tables of mean values obtained from the rate of mortality (Table III) and the duration of the mortality period (Table IV) that no interaction occurs. The table of mean values of the times to initial and final mortalities sets the limits on the duration of the mortality period; but, since the interaction of fluoride concentrations and temperatures act at different rates and times on the time to initial mortality and the time to final mortality, their interaction shows no significant effect on the duration of the mortality period.

It would appear that temperature sets limits for the activity of an organism. When concentrations of fluoride are imposed on these limits, the activity is further restricted. The cost of the physiological regulation required to compensate for these restrictions possibly limits the activity even further.

Conclusions

The concentration of fluoride in the medium has a definite effect on the time to the initial mortality, time to the final mortality, rate of mortality, and duration of the mortality period of rainbow trout. In general, an increase in fluoride concentration brings about an increased number of deaths.

Temperature has an effect on the LC 50's and the sensitivities of rainbow trout to fluoride toxicity. Temperature per se has a significant effect on the time to initial and final mortalities, the rate of mortality, and the duration of the mortality period of rainbow

trout. It is postulated that temperature affects the toxicity of fluoride concentrations because of its effect on the metabolic rate of the fish.

References

1. Ellis, M. M., "Detection and Measurement of Stream Pollution." *Bull. Bur. Fish.*, **48**, 365 (1937).
2. deRoos, C. D., "The Effects of Sodium Fluoride on the Weight Gain and Gills of the Common Goldfish." Thesis, Utah State Univ., Logan, Utah (1957).
3. Neuhold, J. M., and Sigler, W. F., "The Effects of Sodium Fluoride on Carp and Rainbow Trout." *Trans. Amer. Fish. Soc.*, **89**, 4, 358 (1960).
4. Ellis, M. M., Westfall, B. A., and Ellis, M. D., "Determination of Water Quality." Res. Rept. 9, U. S. Fish and Wildlife Service, U. S. Govt. Printing Office, Washington, D. C. (1948).
5. Whittaker, V. P., "Fluorides as Enzyme Inhibitors." Symposium on Fluorides, Univ. Cincinnati (May 11, 1954).
6. Powers, E. B., "Influence of Temperature and Concentration on the Toxicity of Salts to Fishes." *Ecology*, **1**, 95 (1920).
7. Halsband, E., "Untersuchungen uber das Verhalten von Forelle (*Trutta iridea* W. Gibb) and Dobel (*Squalius cephalus* Heck.) bei Einwirkung verschiedener Aussenfaktoren." *Zeits. Fischerei u. Hilfswiss*, **2**, 227 (1953).
8. Job, S. V., "The Oxygen Consumption of *Salvelinus fontinalis*." Univ. Toronto Stud. Biol. Ser. 61; *Public. Ont. Fish. Res. Lab.*, **73**, 1 (1955).
9. Fry, F. E. J., "Effects of the Environment on Animal Activity." Univ. Toronto Stud. Biol. Ser. 55; *Public. Ont. Fish. Res. Lab.*, **68**, 1 (1947).

1961 WATER WORKS OFFICERS

The American Water Works Association officers for the coming year include those shown above.

President: **John W. Cramer**, Senior Partner in the firm of Fulton and Cramer, Lincoln, Nebr.

Vice-President: **William D. Hurst**, City Engineer and Chairman of Commissioners of the Greater Winnipeg Water and Sanitary Districts, Winnipeg, Manitoba.

Secretary: **Raymond J. Faust**, American Water Works Association, 2 Park Avenue, New York 16.

Treasurer: **William J. Orchard**, retired General Manager of Wallace and Tiernan Inc., Belleville, N. J.

STRIPPING KINETICS OF VOLATILE COMPONENTS OF PETROCHEMICAL WASTES

A. F. Gaudy, Jr., R. S. Engelbrecht, and B. G. Turner

While the highly organic nature of petrochemical wastes suggests the possibility of biological treatment, the volatility of many components of such wastes indicates a dual removal mechanism involving both stripping and biological treatment. This may be particularly important when considering treatment by the activated sludge process. Such a dual removal mechanism might be expected to have a marked effect on design loadings and quite possibly on the quantity of sludge produced. Such a duality in the mode of removal may be a decided asset in the treatment of volatile wastes. Alternatively, it may present a complex problem since, while both mechanisms remove the waste, their effects may not be cumulative. The stripping of a large portion of the waste may make it somewhat difficult to maintain and renew the requisite biological population. The tremendous growth of the petrochemical industry would appear to make these aspects worthy of investigation. In the present study, the most logical approach was first to define factors affecting stripping, since the stripping phenomena may be studied separately.

Basic kinetic considerations pertaining to the diffused air stripping of two volatile compounds typically found in petrochemical wastes have been outlined (1). The present studies are extended to other compounds and the factors which affect the course of the stripping process are examined. It was considered particularly important to define further the relationship between the over-all transfer coefficient, ka, and the unit air flow rate, Q_a, since there exist at least two apparently valid expressions for the relationship between these system variables. The applicability of one or the other of these expressions would seem important in extending the work to a joint study of stripping and biological treatment.

In general, the analyses and techniques used were the same as those previously reported (1). Where different experimental equipment, procedure, or analyses were used they are appropriately described.

A. F. Gaudy, Jr., is Assistant Professor of Sanitary Engineering, R. S. Engelbrecht is Professor of Sanitary Engineering, and B. G. Turner is Research Assistant; Department of Civil Engineering, University of Illinois, Urbana, Illinois.

The paper was presented at the 15th Industrial Waste Conference, Purdue University, Lafayette, Ind., May 3-5, 1960.

Results

Effect of Temperature

Since many of the possible constituents of petrochemical wastes are characterized by relatively low boiling points, it would be expected that temperature might exert an appreciable effect on the stripping rate. To gain an insight into the magnitude of its effect, a reaction liquor consisting of acetone in distilled water was used in a series of 8-hr batch-stripping experiments at temperatures of 10 to 40°C.

For these and subsequent experiments, both the size of the aeration tank and the method of introducing diffused air were changed from that used in previous work. The new aeration tank consisted of a 5.6-in. diameter Lucite column, 8.5 ft high. The tank bottom was made from a 0.5-in. thick

circular Lucite plate which, when grooved and fitted with a rubber ring, insured a water-tight seal. Four carborundum cylindrical diffusers, 1 in. long and 7/8 in. in diameter, were mounted on the plate. The tank bottom could be adjusted up or down the length of column in order to vary the depth of submergence of the diffuser assembly. The air supply to each diffuser could be adjusted individually.

For the temperature studies, the equipment was erected in a constant temperature room which provided control to within ± 0.25°C over the temperature range employed. All experiments were conducted at a diffuser submergence depth of 4 ft (19.3 l of aeration liquor) and a unit air flow rate of 900 ml/min/l with all 4 diffusers in operation.

Results of this study, using an acetone system of 1,000 mg/l COD, are shown in Figure 1 where temperature, in degrees centigrade, is plotted against the over-all rate constant, *ka*. The relative increase in *ka* for temperature intervals of 5 and 10°C are given as Q_5 and Q_{10} in Table I. It is seen that Q_5 and Q_{10} values remain essentially constant.

TABLE I.—Effect of Temperature on *ka* in an Acetone-Distilled Water System

Temperature Range (°C)	Q_5	Q_{10}
10–15	1.37	—
15–20	1.36	1.86
20–25	1.34	—
25–30	1.32	1.77
30–35	1.26	—
35–40	1.48	1.88

Relation Between ka and Q_a

The relationship between the proportionality constant *ka* and unit air flow rate Q_a was given by Eckenfelder *et al.* (2) and Hixon and Gaden (3) as:

$$ka = C\,Q_a^n \quad \ldots\ldots\ldots (1)$$

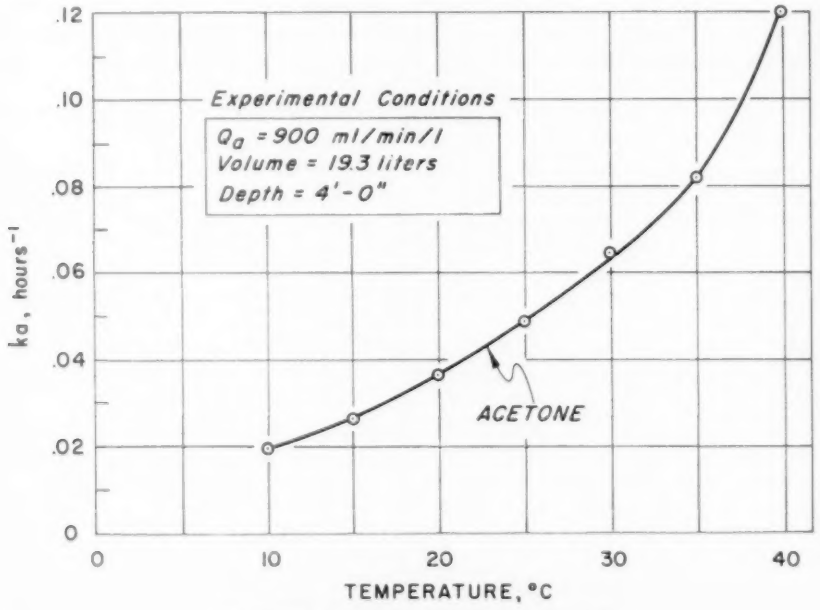


FIGURE 1.—Effect of temperature on *ka*.

and by Engelbrecht *et al.* (1) as

$$ka = ka_o + R\ Q_a \quad \ldots\ldots (2)$$

It seemed possible that both expressions might not be equally applicable under all experimental conditions. Since the exponent n appears to be a function of the means of aeration and the physical aspects of the aeration equipment, it might ideally be employed to determine optimum tank geometry and the efficiency of any specific means of aeration. However, before using such an empirical relationship it is necessary to determine the range of unit air flow rates and experimental conditions for which such an equation would adequately express the effect of the variables.

In an effort to compare the two expressions for ka and to evaluate the effects of experimental variables, a series of experiments was run using the same equipment employed for the temperature studies. Unit air flow rate was varied from 290 to 1,800 ml/min/l at a temperature of 25°C and depth of 4 ft, corresponding to 19.3 l of aeration liquor. As in the case of the temperature studies, all 4 diffusers were placed in operation. Thus, both the size of the aerator and the means of aeration were varied from that used in the previous studies (1); i.e., a 4-ft depth, 19.3-l volume aerator and standard carborundum diffusers were used where the previous studies employed a 38-in. depth, 8.0-l volume aerator, and a drilled diffuser plate with 0.014-in. diameter openings. All values of ka were obtained from the results of hourly COD analyses obtained during an 8-hr batch-stripping experiment using acetone. Results are plotted in Figure 2 on arithmetic coordinates and in Figure 3 on logarithmic coordinates.

Figure 2 shows that a linear relationship exists in the form of $ka = ka_o + R\ Q_a$. Values of R and ka_o taken from the graph are 0.00005 and 0.0022, respectively, which agree fairly well with those obtained with the smaller Lucite column and aerator assembly previously used (1). In Figure 3 the data, as in the previous studies, approximate a linear relationship yielding the equation $ka = C\ Q_a^n$. The value of n computed from this plot was found to be in the order of 1.0. When the scatter of the points is considered, this

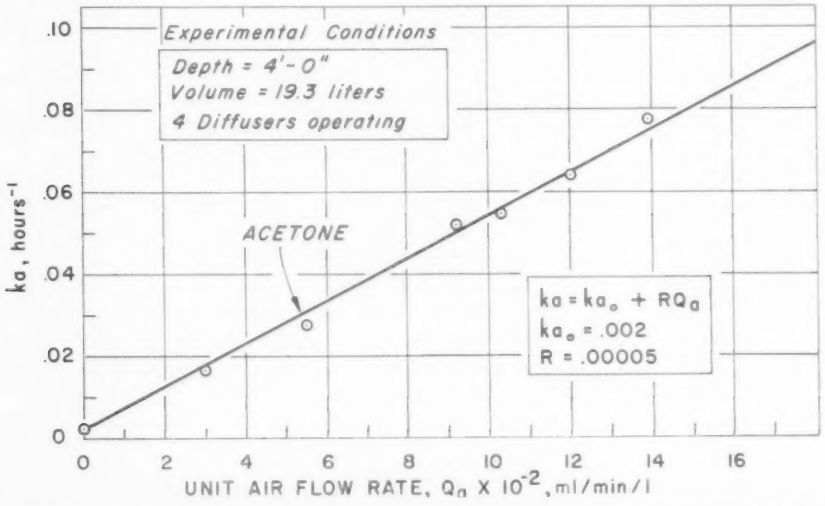


FIGURE 2.—Effect of unit air flow rate on ka for a confined column (arithmetic plot).

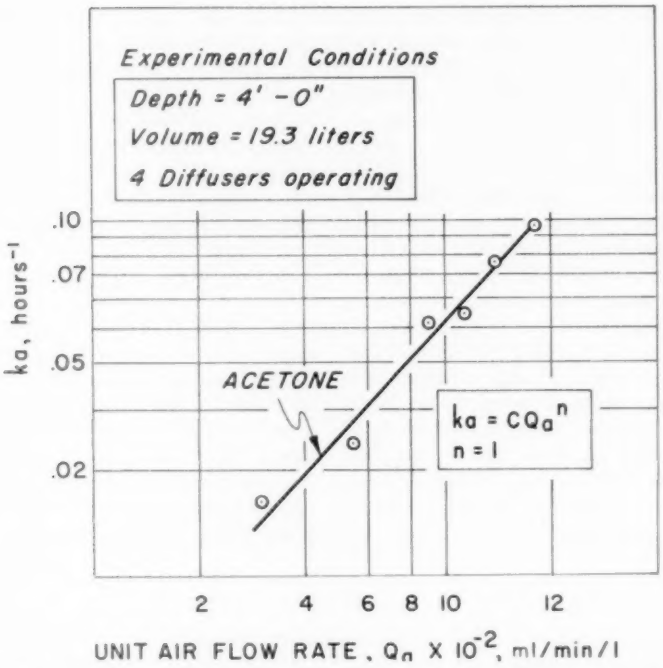


FIGURE 3.—Effect of unit air flow rate on *ka* for a confined column (log-log plot).

value compares fairly well with the n value of 0.85 found for the smaller Lucite column. It is interesting to note that a value of $n = 1$ for the equation $ka = C\,Q_a^n$ predicts a linear equation. Although both the size of aeration tank and means of aeration were changed from that previously used, the tank geometry was similar. Both cylindrical tanks may be considered as "confined columns" of aeration liquor (4). The liquid was not subject to the rolling action prevalent in some types of activated sludge tank.

Unit Air Flow Rate vs. ka at Various Depths

Using the large Lucite column a series of experiments was undertaken at 25° C in which both the tank depth and unit air flow rate were varied. Acetone in distilled water was again used as the aeration liquor. The air flow rates employed were 300, 600, and 900 ml/min/l and the depths were 2, 4, and 6 ft. As before, values of *ka* were calculated for each experiment from eight hourly COD analyses made during the course of a batch experiment. In the studies in which unit air flow rate was varied from 290 to 1,800 ml/min/l at the 4-ft depth, all four diffusers of the aeration assembly were functioning at all times; i.e., Q_a was varied merely by admitting a greater air flow through each diffuser. Since the velocity of efflux could conceivably affect the bubble size, it was decided in these experiments to increase the air flow by using one, two, or three diffusers corresponding to the three air flows used. Since Q_a was increased by including additional diffusers, the emerging bubble size could be expected to be the same at each Q_a employed. Regardless of the number of diffusers in operation, there was in no case a

pronounced cone of bubble dispersion. In all cases, the entire column was packed with bubbles at a distance of two inches above the diffuser assembly.

The experimental results are shown in Figure 4, wherein ka is plotted against depth for the three unit air flow rates employed. The effect of depth of submergence of the aeration assembly on the over-all velocity constant, or transfer coefficient ka, is dependent on unit air flow rate. At the lower Q_a (300 ml/min/l) depth had no effect on ka. It had a slight effect at 600 ml/min/l and a still greater effect at 900 ml/min/l. However, even at the highest Q_a employed, the effect of depth of submergence on ka is small compared with the effect of unit air flow rate, as seen by an inspection of the ordinates at any given depth.

It is also apparent from Figure 4 that the relationship between ka and Q_a, under the experimental conditions employed, does not retain its former linearity. However, it may be argued that three points, no matter how carefully obtained, are not sufficient to quantitatively establish a trend. Comparison of these results at the four-foot depth with those plotted in Figure 2 shows that in general the points fall within the range of scatter of the data from which a linear relationship was concluded. Alternatively, the downward concavity of the points could be attributed to the change in the method of regulating the unit air flow rate. In any event, the effect of depth on the relationship between ka and Q_a would appear to be slight for confined column experiments. This is in general accord

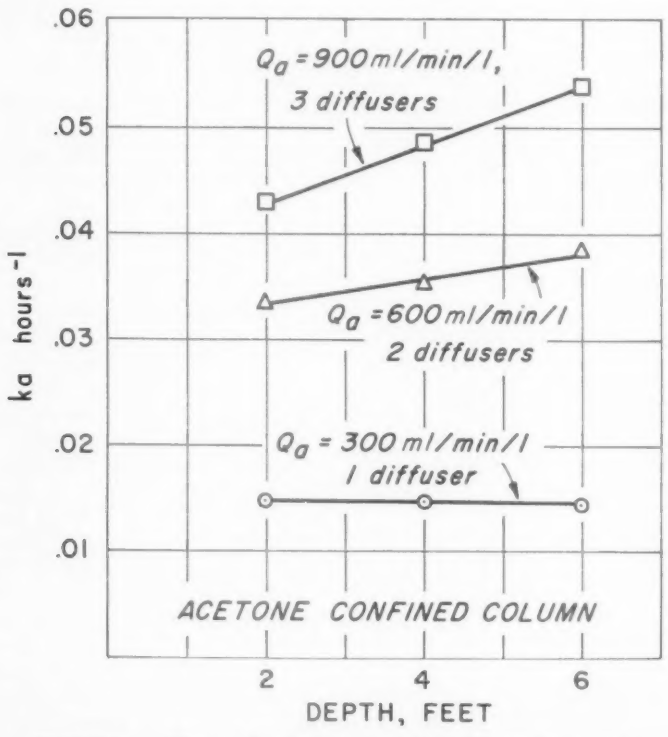


FIGURE 4.—Effect of depth on ka at various unit air flow rates.

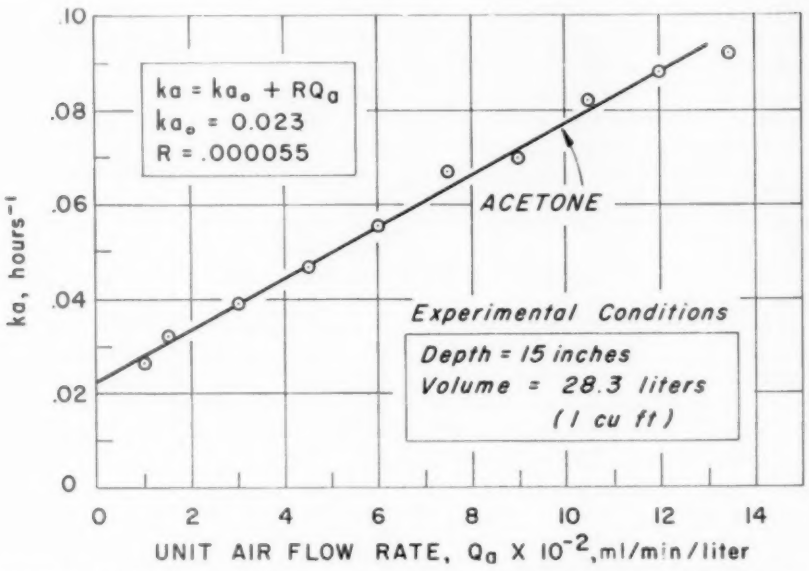


FIGURE 5.—Effect of unit air flow rate on *ka* in a conventional aerator (arithmetic plot).

with the recent findings of Eckenfelder (5) concerning oxygen absorption.

Effect of Tank Geometry on ka and Q_a

Results reported thus far were obtained using an aeration tank that may be defined as a confined column. However, the geometric construction and location of aeration equipment in many activated sludge tanks is such as to enhance a rolling rather than a shearing action.

In order to examine the possible effect this type of geometry might have on the relation between *ka* and Q_a, an aeration tank of the following dimensions was constructed: 18 in. deep, 12 in. long, 15 in. wide, 15 in. of aeration liquor depth, and 28.3 l of volume.

The longitudinal walls and bottom were molded from a single piece of Lucite. The junction of side wall and tank bottom was made in a one-inch radius curve, to simulate a beveled wall and enhance a rolling action. Air was introduced through a cylindrical carborundum diffuser, 1.75 in. in diameter and 9 in. long, placed horizontally along a longitudinal wall and located 0.5 in. above the tank bottom. Experiments were conducted at 25°C, using an acetone-distilled water liquor and various unit air flow rates. As before, all *ka* values were obtained from a semi-log plot of eight hourly COD samples taken during a batch-stripping experiment. In all experiments, the COD was removed in accordance with first order kinetics.

The results are plotted on arithmetic coordinates in Figure 5 and on log-log coordinates in Figure 6. *R*, calculated from Figure 5, was found to be 0.000055, which compares very well with the value obtained in the confined column studies. Ka_o is 0.023 which is approximately 10 times greater than that obtained in confined column studies. From these results it appears that the tank geometry has little effect on the rate of increase of *ka* with unit air flow rate, but that the increased tank surface area brings about an increase in ka_o. The most noticeable effect is to

shift the curve upward (Figures 2 and 5). Since the amount of turbulence appeared to be substantially less than in the confined column studies, while the rate of increase in ka with increasing Q_a remained almost the same, it seems that turbulence is a minor factor in determining ka. This is in accord with the conclusions of Eckenfelder *et al.* (2).

Figure 6, however, shows that the tank geometry has an appreciable effect on the log-log plot, $ka = C\,Q_a^n$. In this case the trend of the data yields unmistakably a curve. It appears that, for this type of aeration tank at least, the relation $ka = C\,Q_a^n$ breaks down and cannot be used to relate the variables throughout the experimental range of Q_a values.

Stripping Behavior of Selected Aldehydes

According to results of the previous studies (1) and of the present study, the stripping of acetone and methyl ethyl ketone follows first order kinetics. However, it was not known whether this would hold true for other volatile compounds. Of particular interest were the volatile aldehydes, since they are known to be extremely reactive. It seemed possible that, even though oxygen is a relatively mild reagent, it could effect an oxidation to the corresponding and possibly less volatile acid.

Accordingly, the stripping kinetics of propionaldehyde, butyraldehyde, and valeraldehyde were examined. The procedures employed were in general accord with those previously described. The aeration unit used was the 28-l tank described above. Because of the activity of the aldehydes, it was decided to analyze directly for the aldehyde group in addition to performing COD analyses. A colorimetric test for the aldehyde group using 3,5-dinitrosalicylic acid was employed (6). Thus, it was possible to compare the rate of

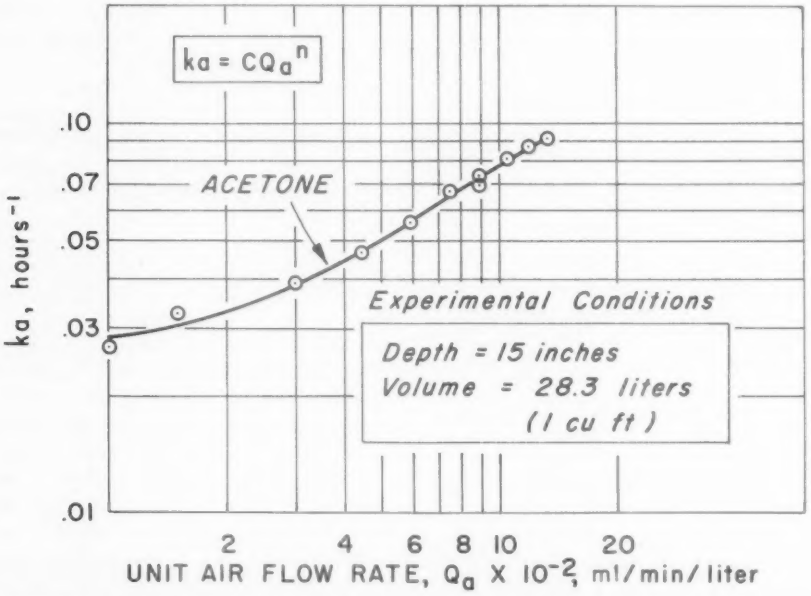


FIGURE 6.—Effect of unit air flow rate on ka in a conventional aerator (log-log plot).

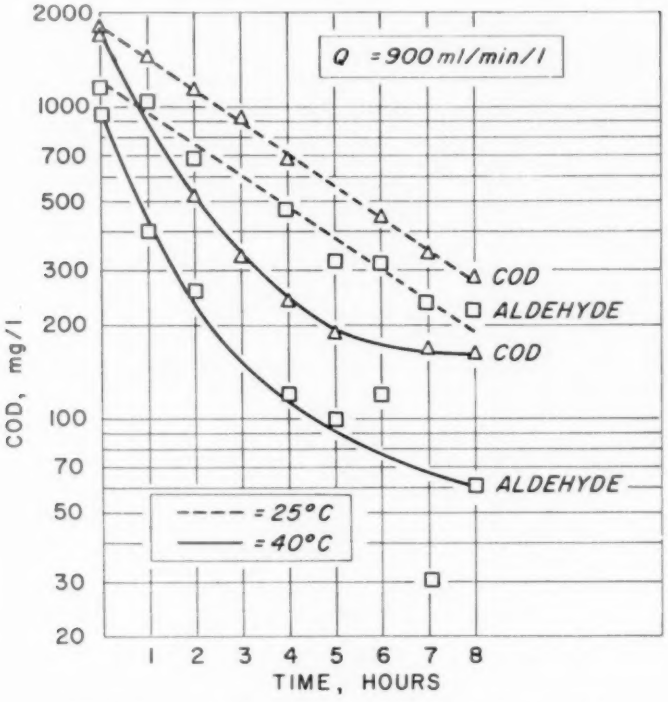


FIGURE 7.—Stripping of propionaldehyde at 25 and 40°C.

aldehyde removal with that of COD removal.

Results of stripping studies using propionaldehyde are shown in Figure 7. At 25°C the removal follows first order kinetics, and the removal of the aldehyde parallels the removal of COD. From these results it appears that at 900 ml/min/l and 25°C, the aldehyde is not oxidized to the acid. However, this may not be true at a temperature of 40°C. If the aldehyde has a tendency to be oxidized to the acid it would be expected to be magnified at 40°C. Results shown in Figure 7 indicate that first order kinetics no longer describe the stripping of propionaldehyde at this elevated temperature. It is also seen that the aldehyde and COD curves diverge as time increases; that is, the aldehyde disappears faster than the COD. This may be taken as indirect evidence that the aldehyde may be oxidized. Since the oxidation product, propionic acid, is less volatile than the aldehyde, it would be expected that the COD would remain high while the aldehyde decreased.

Results of studies using butyraldehyde and valeraldehyde are shown in Figure 8. The unit air flow rate was 900 ml/min/l and the temperature 25°C. From these results, it appears that for these compounds first order kinetics do not adequately characterize the rate of removal.

The per cent removals obtained for the various compounds studied are compared in Table II. All results were obtained using the rolling action tank with a volume of 28.3 l. Regardless of the order of reaction for butyraldehyde and valeraldehyde, a substantial removal of COD may be ef-

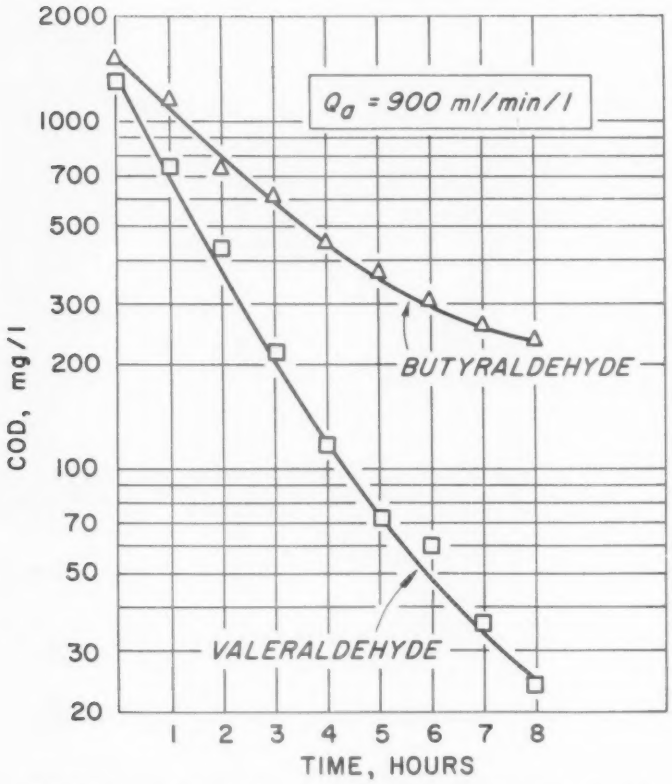


FIGURE 8.—Stripping of butyraldehyde and valeraldehyde at 25°C.

fected in an eight-hour aeration period. However, 900 ml/min/l or 7.2 cfh/gal represents a large expenditure of air, possibly in excess of that applied in the prototype activated sludge process.

Summary and Discussion

It has been shown in these aeration studies that first order kinetics cannot be assumed to hold for all volatile compounds. While acetone, butanone, and propionaldehyde, at 25°C, are removed at a rate which is constantly proportional to the amount remaining at any time, butyraldehyde, valeraldehyde, at 25°C, and propionaldehyde, at 40°C, are not. This may be due to the oxidation of the aldehyde to the corresponding acid. The results using propionaldehyde indicate that the effect is temperature-dependent.

TABLE II.—Removal of Volatile Compounds After 8 hr Aeration at 900 ml/min/l and 25°C

Compound	Per Cent Removal
Acetone	72
Propionaldehyde	85
Butyraldehyde	85
Valeraldehyde	98

Concerning the two alternate empirical relationships between the overall proportionality constant, or transfer coefficient ka, and the unit air flow rate, it is felt that the linear expression suffices to express the relationship over a wider range of experimental conditions and unit air flow rates than

does the logarithmic expression. The log-log plot has been used by Hixson and Gaden (3) to express oxygen absorption data and by Eckenfelder *et al.* (2) for stripping data. In general, it is a widely accepted form. As seen by the results of this study, the use of such a plot may become objectionable when such a relation is extrapolated. Such is the case when constants are evaluated from the graph using Equation 1. That is to say, this expression is not as general as is implied by the formula. It is not suggested that Equation 2 is more fundamental; it was found, however, that it did suffice to relate the variables over a wider range of experimental conditions. The use of the logarithmic expression is, in one respect, advantageous since, as suggested by Hixson and Gaden (3), n appears to be most closely related to the method of introducing diffused air, which in turn affects the bubble size and hence the ratio of volume to area available for mass transfer. However, the advantage of the specificity of n in being a measure of the effectiveness of the method of aeration becomes a liability in the over-all applicability of the expression when the tank geometry is such that tank cross-section increases in relation to its volume. In this case, an entirely different mode of mass transfer, namely the diffusion across the interface between the total mass of aeration liquor and the atmosphere, significantly contributes to the over-all transfer as measured by COD removal. At the higher unit air flow rates, this contribution is masked.

It is interesting also to analyze the arithmetic relationship in the light of tank geometry. In this case Equation 2 does not break down. The major effect of transfer across the interface between the total volume under air and the atmosphere is to move the curve upward by a factor Δka_o. That is, the contribution to the over-all transfer coefficient by this mode of removal is registered as an increase in ka_o while Equation 2 still suffices to express the variables. The fact that this relationship still holds may be taken as partial evidence that the contribution from mixing alone, which is certainly increased by an increase in unit air flow rate, is a comparatively minor factor in determining ka since its effect, if significant, would cause a concavity in the plot.

The results tend to emphasize the empirical nature of the expressions and the need for caution in employing them to relate experimental variables. This appears to be especially important in studying removal of volatile compounds by the joint action of stripping and biological activity.

Conclusions

The following conclusions have been drawn:

1. It cannot be assumed that all volatile compounds will, under any condition, be stripped in accordance with first order kinetics.

2. The empirical expression $ka = ka_o + R\,Q_a$ appears to be a more generally applicable relationship than the equation $ka = C\,Q_a{}^n$. The use of the latter expression is, in some respects, more desirable but the range of its applicability must first be experimentally determined for any specific set of experimental conditions.

3. Factors most prominently affecting the stripping of a specific volatile compound are temperature, unit air flow rate, and tank geometry.

Acknowledgments

This investigation was supported by a research grant, RG 4443, from the National Institutes of Health, U. S. Public Health Service. Appreciation is extended to Mr. R. S. Schaefer for his assistance in the laboratory work.

References

1. Engelbrecht, R. S., Gaudy, A. F., Jr., and Cederstrand, J. M., "Diffused Air Stripping of Volatile Waste Components of Petrochemical Wastes." THIS JOURNAL, **33**, 2, 127 (Feb. 1961).
2. Eckenfelder, W. W., Kleffman, R., and Walker, J., "Some Theoretical Aspects of Solvent Stripping and Aeration of Industrial Wastes." *Proc. 11th Ind. Waste Conf.*, Purdue Univ., Ext. Ser. **91**, 14 (1957).
3. Hixson, A. W., and Gaden, E. L., Jr., "Oxygen Transfer in Submerged Fermentation." *Ind. Engr. Chem.*, **42**, 1792 (Aug. 1950).
4. Morgan, P. F., and Bewtra, J. K., "Air Diffuser Efficiencies." THIS JOURNAL, **32**, 10, 1047 (Oct. 1960).
5. Eckenfelder, W. W., Jr., "Factors Affecting the Aeration Efficiency of Sewage and Industrial Wastes." *Sewage and Industrial Wastes*, **31**, 1, 60 (Jan. 1959).
6. Carter, H. E., *et al.*, "Experimental Biochemistry." Stipes Publishing Co., Champaign, Ill. (1959).

MEETINGS OF INTEREST

Apr. 10–14	**American Society of Civil Engineers,** Hotel Westward Ho, Phoenix, Ariz. W. H. Wisely, ASCE, 33 West 39th St., New York 18.
Apr. 17–18	**Fourth Conference on Great Lakes Research,** University of Michigan, Ann Arbor, Mich. Dr. Charles F. Powers, Great Lakes Research Division, 1119 Natural Science Building, Ann Arbor, Mich.
May 2–4	**16th Purdue Industrial Waste Conference,** Purdue University, Lafayette, Ind. Professor Don E. Bloodgood, School of Civil Engineering, Purdue University, Lafayette, Ind.
May 5	**9th Annual Pennsylvania Clean Streams and Clean Air Conference,** Penn Harris Hotel, Harrisburg, Pa. Pennsylvania State Chamber of Commerce, 222 North Third St., Harrisburg, Pa.
May 10–12	**American Institute of Chemists,** Hotel Statler, Washington, D. C.
May 25–26	**10th Pacific Industrial Waste Conference,** Washington State University, Pullman, Wash. William H. Knight, Washington State Institute of Technology, Washington State University, Pullman, Wash.
May 29–June 3	**International Water Supply Association, Fifth Congress,** Congress Hall, West Berlin, Germany. International Water Supply Association, 34 Park St., London W. 1, England.
June 4–9	**American Water Works Association,** Cobo Hall, Detroit, Mich. Raymond J. Faust, AWWA, 2 Park Ave., New York 16.
June 5–7	**7th Sewage Works School for Operators,** Washington State University, Pullman, Wash. William H. Knight (see address above).
June 8–10	**Manufacturing Chemists' Association,** Greenbrier, White Sulphur Springs, W. Va.
June 11–14	**Air Pollution Control Association,** Commodore Hotel, New York, N. Y.
June 19–21	**Rudolfs Research Conference,** Department of Sanitation, Rutgers University, New Brunswick, N. J. Dr. H. Heukelekian, Chairman, Dept. of Sanitation, Rutgers University.

COMPARISON OF CHLORINE DETERMINATION METHODS IN WASTEWATERS

M. C. Rand and Joseph V. Hunter

These studies resulted from a discussion concerning the "best" method of determining the chlorine demand of a certain industrial waste. Since such determinations are involved in the charges for treatment of the waste, and represent appreciable sums of money, the discussion of methods was by no means purely academic.

No one method for this determination is recognized as being the best in all circumstances. Since the use of various techniques often produces differing results with the same sample, the best choice of method for any given situation is the one which produces results which are most meaningful in terms of the realities of that particular situation. Stated differently, the best method is that which gives results of the greatest practical usefulness. It follows from this that different circumstances may call for the use of different methods or techniques.

The studies reported here consist essentially of a comparison among several alternative techniques, which are based on modifications of the orthotolidine method, the amperometric method, and the bacteriological chlorine requirement test. The variation of results among the methods was examined, as well as the reproducibility of each method in different laboratories.

M. C. Rand was Chief Chemist of the Middlesex County Sewerage Authority, Sayreville, N. J., when the paper was presented. He is now Associate Professor in the Department of Civil Engineering, Syracuse University, Syracuse, N. Y. Joseph V. Hunter is Lecturer in Sanitation at Rutgers University, New Brunswick, N. J.

Nature of the Waste

The waste used in these studies originated from flax pulping and the manufacture of specialty papers, and consists principally of wash waters, black liquor, and whitewater. A substantial portion of the black liquor is excluded from the waste stream, but that portion of it which remains in the pulp after filter-pressing finds its way to the sewer in the wash water. The combined waste is dark brown in color. Average figures showed the BOD to be 924 mg/l and suspended solids 963 mg/l, but individual samples deviate from the averages by as much as 50 per cent. The pH is normally in the range of 8.0 to 9.5.

Methods

Five distinct procedures were examined, any of which might conceivably serve as a means of evaluating the amount of chlorine needed for treatment of the waste. In simplified form, the procedures are outlined as follows.

1. A sample of waste was diluted with nine volumes of distilled water, and this diluted sample was used to determine the chlorine dosage required to produce 0.1 mg/l of residual chlorine after 15 minutes' contact, as measured by the orthotolidine method. Ten (the dilution factor) times the dosage so determined was recorded as the "orthotolidine chlorine demand."

2. A sample of waste, diluted with nine volumes of distilled water, was used to determine the chlorine dosage required to produce 0.1 mg/l of residual chlorine after 15 minutes' contact, as

measured by the amperometric method. The resulting dosage figure was also multiplied by the dilution factor of 10 for purposes of comparison.

3. Undiluted waste was used to determine the chlorine dosage required to produce 0.1 mg/l of residual chlorine after 15 minutes' contact, as measured by the amperometric method. This dosage figure is recorded as the "amperometric chlorine demand."

4. Undiluted waste was used to determine the chlorine dosage required to produce 5.0 mg/l of residual chlorine after 15 minutes' contact, as measured by the amperometric method.

5. Using a mixture containing 90-per cent domestic sewage and 10-per cent waste, the chlorine dosage was determined which was required to reduce the coliform index of the mixture to 10 organisms per 100 ml. The figure recorded as the "bacteriological chlorine requirement" of each sample was derived from this determined dosage by correcting for the corresponding requirement of the domestic sewage in the mixture, and for the dilution of the waste by the sewage. The details of this procedure and calculation are elaborated later in this paper.

Actually, procedures 1 and 2 were performed simultaneously on the same sample. Subsamples of the diluted waste were measured into a series of beakers, to which various volumes of standardized chlorine water were added with stirring, to insure its prompt and uniform distribution. After exactly 15 minutes' contact, measured portions were transferred to small beakers containing the orthotolidine reagent, and to large beakers containing the reagents for the amperometric test. Residuals were thus determined separately by the two methods.

Likewise, tests 3 and 4 were performed on a single series of chlorinated samples by extending the range of chlorination doses to produce both the desired residual values.

The source of chlorine was chlorine water, of a concentration not less than 1.0 mg/ml freshly prepared daily and standardized immediately prior to its use.

Because the waste in question was quite alkaline, certain preliminary tests were performed to insure that the pH was in the correct range during the residual chlorine determinations. For the orthotolidine test, the reagent was added to a sample of diluted but unchlorinated waste, and the pH was measured to insure its being 1.3 or lower. In every case, it was found that the acidity of the reagent was sufficient to produce the desired pH, making the addition of more acid unnecessary.

In using the amperometric method, a preliminary test was run to insure that the amount of buffer added was sufficient to reduce the pH of the undiluted waste to 4.0. Again, it was found that satisfactory pH values were obtained without special modification of the test procedures.

The temperatures of the samples and dilution were between 20 and 25°C when the tests were performed.

The detailed technique of the chlorine requirement test was as follows. A preliminary test sample was prepared, consisting of one volume of waste and nine volumes of domestic sewage. The pH of the mixture was measured, and if it was above 8.0, the amount of acid required to reduce it to 8.0 was determined by titration. After titration, the sample was treated with chlorine equivalent to the highest dosage planned for the chlorine requirement test. If this dosage of chlorine depressed the pH below 7.0, the sample was titrated to pH 7.0 with sodium bicarbonate.

After these preliminary tests, a new portion of the undiluted waste was treated with the amount of acid determined in the first titration of the preliminary tests. One volume of the waste so treated was mixed with nine volumes of domestic sewage. If the

preliminary test showed that sodium bicarbonate was required to prevent chlorination from reducing the pH below 7.0, the required quantity was added to the mixture at this point. The mixture was then divided into subsamples, which were chlorinated. After 15 minutes' contact, a 100-ml portion of each subsample was dechlorinated by treatment with 100 mg of solid sodium thiosulphate. If desired, other portions were treated as required for residual chlorine determinations. From the bacteriological sample, 10 one-ml portions were planted in lactose broth, and positive tubes were confirmed in brilliant green bile broth. The entire procedure, as applied to the mixture of sewage and industrial waste, was simultaneously performed on the domestic sewage alone, without added waste.

The chlorine requirement of the waste was calculated as follows. The lowest dosage of chlorine which produced less than two positive confirmed tubes was taken as the chlorine requirement of the sewage-industrial waste mixture M. Likewise, the lowest dosage producing less than two positive confirmations in the domestic sewage was taken as the requirement of the domestic sewage S. The chlorine requirement of the industrial waste alone W was calculated by correcting the chlorine requirement of the mixture for dilution and for the chlorine requirement of the sewage by applying the formula $W = 10(M - 0.9S)$.

Discussion of Methods

The orthotolidine chlorine demand tests were performed on waste samples which had been diluted tenfold with distilled water. This modification was introduced in order to overcome the intense color of the undiluted waste, which obscured the orthotolidine color.

Theoretically, this modification is open to certain questions. It might be argued, for example, that a residual chlorine concentration of 0.1 mg/l in the diluted waste is equivalent to a concentration of 1.0 mg/l in the undiluted material, and that the corresponding chlorine dosage in the diluted sample might therefore be erroneously high. On the other hand, the residual chlorine concentration of 0.1 or 1.0 mg/l is so small in proportion to the dosage required to produce any residual chlorine after 15 minutes' contact that the uncertainty produced by this consideration may be negligible.

Also on theoretical grounds, it might be anticipated that the lower concentrations of both waste and chlorine resulting from use of diluted samples would retard the rate of reaction, so that residual chlorine would appear with lower doses applied than as if undiluted waste had been used. However, if the major part of the chlorine is consumed in relatively rapid reactions with inorganic constituents of the waste, and only a small part in slower reactions, then again the difference produced by dilution of the samples may be insignificant.

In order to evaluate the practical effects of these conflicting possibilities, the results obtained with diluted and undiluted samples were compared. This could not be done by means of the orthotolidine method, because of the strong color of the undiluted waste. The comparison was possible, however, with the amperometric method. This is the reason for the inclusion in Table I of the column of results obtained by the amperometric method on the diluted waste (Column 3). Only one of the laboratories performed this test.

The dosage to a residual of 5.0 mg/l by the amperometric method was determined because of a suspicion that this dosage might correspond to the "bacteriological chlorine requirement" and the "orthotolidine chlorine demand" more closely than would the "amperometric chlorine demand."

The method described for determining the "bacteriological chlorine requirement" is basically that described

TABLE I.—Comparison of Results Obtained in Two Laboratories

Sample No.	10-Per Cent Industrial Waste, 90-Per Cent Distilled Water			Samples Undiluted				10-Per Cent Industrial Waste, 90-Per Cent Sewage	
	Dosage to 0.1 mg/l* OT (OT Demand)		Dosage to 0.1 mg/l* Amper.	Dosage to 0.1 mg/l* Amper. (Amper. Demand)		Dosage to 5.0 mg/l* Amper.		Dosage to Coliform MPN 0.1/cc*	
	(1) Lab A	(2) Lab B	(3) Lab A	(4) Lab A	(5) Lab B	(6) Lab A	(7) Lab B	(8) Lab A	(9) Lab B
1	173	185	114	95	73	262	139	130	81
2	231	230	—	130†	128†	—	—	—	—
3	214	172	—	107†	123†	289†	—	265	110
4	132	115	43	84	56	126	109	—	—
5	225	238	148	100	100	269	157	270	140
6	151	157	76	64	58	134	113	—	—
7	220	225	144	114	120	303	186	192	175
8	240	220	—	—	—	—	—	—	—
9	174	170	81	102	84	157	128	204	168
10	249	221	139	124	92	375	144	—	—
11	285	250	179	188	91	368	146	347	360
12	206	222	146	176	68	236	119	—	—
13	303	283	84	198	88	287	117	303	341
14	312	336	190	197	74	272	109	—	—
15	271	294	139	148	95	230	146	188	294
16	153	144	117	111	54	140	92	—	—
17	390	264	254	227	87	488	150	333	295
18	220	203	154	141	49	402	90	—	—
19	274	217	121	131	53	278	97	257	258
20	249	254	234	201	82	286	111	—	—
Avg	234	220	139	141	80	271	126	249	222

* All dosages are expressed in mg/l, on the basis of undiluted waste.
† Not included in average.

in "Standard Methods" (1). The minor variations of technique introduced were those considered desirable by the various persons interested in this work.

TABLE II.—Further Comparison of Alternative Methods

Sample Number	OT Demand (mg/l)	Amper. Demand (mg/l)	Requirement (mg/l)
21	338	111	311
22	515	265	292
23	380	208	299
24	835	81	565
25	293	240	173
26	473	165	565
27	520	208	690
28	508	361	390
29	477	415	502
30	536	300	429
31	513	456	464
32	621	444	771
Avg	501	271	454

Results

Table I summarizes the comparison of two laboratories' results in the various tests. Averages are included, despite the prevalent suspicion that they may be misleading in work of this kind. For the immediate practical purposes of these studies, averages were important, since in effect they determine the treatment costs.

Additional comparisons, not between laboratories, but among the "orthotolidine chlorine demand," the "amperometric chlorine demand," and the "bacteriological chlorine," are presented in Table II.

Discussion of Results

From a study of Table I, several interesting comparisons are possible.

The first comparison is in the first and second columns of data, showing the two laboratories' results in the "orthotolidine chlorine demand" test. The over-all agreement, showing 6.4-per cent difference between the averages, is considered satisfactory. The agreement between laboratories on the individual samples was also good, except for two or three samples of the 20. Since each laboratory performed only a single determination on each sample, rather than a set of replicates, the analytical uncertainty of the single determinations is also reflected in the table. Considering all 20 samples, the mean deviation between laboratories was 24.4 mg/l, or 10.7 per cent, which, it is believed, will be considered as good a record as could be expected.

Next, are compared Columns 3 and 4 of Table I, which present the "amperometric chlorine demand" as determined on diluted and undiluted samples in the same laboratory. Here, the agreement on individual samples was not as good, the mean deviation being 24.4 mg/l, or 17.4 per cent. Yet, there was a difference of only 2 mg/l, or 1.4 per cent, between the averages, which in actual practice determine the charges for treatment. The extremely close agreement between averages may not be reproducible, since random elimination of almost any one of the 17 samples would increase the difference. Nevertheless, there is a strong indication that no consistent difference in observed chlorine demand results from dilution of the sample. Strictly speaking, this conclusion can be applied only to the particular waste tested. It would be interesting to investigate whether the same is true of other industrial wastes and sewages. Also, these experiments employed the amperometric method of determining residual chlorine, and there may be some danger in assuming that the same conclusion would result from use of another method. Regardless of the method and the reactions used for determining residual chlorine, however, the reactions between the waste and the applied chlorine remain essentially unchanged. It thus seems quite probable, at least, that with the particular waste studied, tenfold dilution, if it is taken into account in the calculations, can be said to produce no systematic change of chlorine demand.

Next, Columns 4 and 5 should be compared, the two laboratories' determinations of amperometric chlorine demand. Here, a really serious discrepancy exists. It is particularly interesting to note that the early samples, perhaps the first 10, show reasonably good agreement, but from there on the results begin to differ very markedly, so that a large difference appears in the over-all average. The results obtained by Laboratory A show a constant or slightly increasing ratio to the "orthotolidine chlorine demand," while in Laboratory B's results this ratio decreases sharply. It should be emphasized that no detectible difficulty of operating the amperometric apparatus was observed by either laboratory during this period.

The same effect is evident in comparing Columns 6 and 7 of Table I.

Considering Columns 8 and 9, it is apparent that the replicate determinations of the "bacteriological chlorine requirement" of a given sample often show appreciable difference, largely due, it is believed, to the low precision of the measurement of the coliform index of the chlorinated subsamples. Here again, the averages of the 10 samples tested by the two laboratories showed relatively good agreement.

It was pointed out that the dosages required to produce an amperometric residual of 5.0 mg/l (Table I, Columns 6 and 7) were determined for comparison with the "bacteriological chlorine requirement" (Columns 8 and 9). However, the results obtained by the

two laboratories were so divergent that the comparison is clouded. Considering only the results in Column 6, it appears possible that the "bacteriological chlorine requirement" would correpond to an amperometric residual of slightly less than 5.0 mg/l. On the other hand, the figures in Column 7 indicate that the amperometric residual corresponding to the "bacteriological chlorine requirement" is much higher.

Comparing Columns 1 and 2 with Columns 8 and 9 indicates that for the waste under study, the "orthotolidine chlorine demand" and the "bacteriological chlorine requirement" are generally of very similar magnitude. On the other hand, the "amperometric chlorine demand" shown in Columns 4 and 5 tends to be much lower. The same trends are evident in Table II, which presents additional data comparing the three determinations.

To summarize, the two laboratories agreed rather well in the determinations of "orthotolidine chlorine demand" and "bacteriological chlorine requirement," and found the two values to be of approximately the same order of magnitude. The "amperometric chlorine demands," however, were lower, and the two laboratories' results differed seriously.

The reason for the lack of agreement in respect to the "amperometric chlorine demand" cannot be clearly defined at present. It was observed that most samples, after 15 minutes' reaction with chlorine and dechlorination by excess phenylarsine oxide, still contained substances capable of reaction with iodine, as evidenced by fading end points in the back titration. This could lead to differences in the observed "amperometric chlorine demand" if there is a difference in the speed of reaction with excess iodine among various electrodes. Electrodes which react quickly would then show the end point with a smaller volume of added iodine, resulting in a high value of residual chlorine for a given dosage, and a low chlorine demand. Electrodes reacting more slowly would give the opposite effect.

Conclusions

1. Determinations of the "orthotolidine chlorine demand" of samples of a strong industrial waste in two laboratories showed fairly good agreement.

2. Determinations of "bacteriological chlorine requirement" agreed reasonably well between laboratories.

3. Under the prescribed test conditions, the "orthotolodine chlorine demand" and the "bacteriological chlorine requirement" were of similar magnitude.

4. "Amperometric chlorine demands" determined in the two laboratories agreed poorly.

5. Both laboratories found the "amperometric chlorine demand" appreciably lower than the other values determined.

6. The reason for the poor agreement in the "amperometric chlorine demand" is not yet established. One possible explanation has been discussed briefly, and further studies are underway.

7. Tenfold dilution of the samples, if taken into account in the calculations, produced no systematic change in the observed values of chlorine demand.

Reference

1. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York (1955).

SALT TOXICITY IN ANAEROBIC DIGESTION

Perry L. McCarty and Ross E. McKinney

In the control of anaerobic digestion one of the most frequent problems which arises is a large increase in the volatile acid concentration. Following such a rise in volatile acids, a decrease in the activity of the methane-producing organisms has been noted regardless of the pH maintained. This has usually been noted when the volatile acids exceed 2,000 to 6,000 mg/l and has commonly been attributed to "volatile acid" toxicity. McCarty and McKinney (1), however, have shown from the effect of various sodium salts on acetate fermentation that this decreased activity is due to "salt" toxicity. Thus, a rapid buildup of volatile acids and subsequent neutralization with alkaline materials is similar to a slug loading of volatile acid salts, and the detrimental effect observed is identical to that obtained when adding equivalent amounts of other common salts.

Salt toxicity has been studied for many years in the biological field. By applying the knowledge gained through these studies to the effect of high volatile acid concentrations on the methane-forming bacteria, a better understanding of the anaerobic digestion process can be obtained, which will aid in the control of digestion and in determining the cause and effect of high volatile acid concentrations.

Nature of Salt Toxicity

Salt toxicity was studied extensively in the biological field prior to 1930 and much of this early work was summarized by Falk (2). Although the cations of salts in solution must always be associated with the anions, the toxic action of salts was found to be predominantly determined by the cation. The role of the anions was relatively minor and largely associated with their effect on properties such as the pH of the media. In general, monovalent cations, such as sodium and potassium, were less toxic than the divalent cations, such as calcium and magnesium, when compared on a molar concentration basis. The toxic effect of cations, however, varied widely from organism to organism, certain species being able to tolerate much higher concentrations than others.

Another important aspect of salt toxicity was that of salt antagonism, or the ability of a nontoxic cation to remove the effect of a toxic one. For example, Abelson and Aldous (3) found the toxicity of manganese, zinc, cadmium, cobalt, and nickel to *E. coli* could be lowered by the presence of high concentrations of magnesium. MacLeod and Snell (4) found that the toxicity of sodium to lactic acid bacteria could be relieved by an increase in the potassium ion concentration.

Applying this knowledge to anaerobic digestion, it may be hypothesized that toxicity resulting from a

Perry L. McCarty is Assistant Professor of Sanitary Engineering, and at the time this paper was presented Ross E. McKinney was Associate Professor of Sanitary Engineering, both at the Massachusetts Institute of Technology, Cambridge, Mass. Ross McKinney is now Professor of Sanitary Engineering at the University of Kansas, Lawrence, Kans.

The paper was presented in full at the Annual Meeting, New York Sewage and Industrial Wastes Assn., New York, N. Y., Jan. 20–22, 1960.

This covers the portion on salt toxicity and an earlier paper included the discussion of volatile acid toxicity.

TABLE I.—Typical Analysis of Acclimated Sludge Seed

Determination	Amount
Alkalinity (mg/l)	2,560
Ammonia nitrogen (mg/l)	128
Organic nitrogen (mg/l)	256
Total solids (per cent)	0.80
Volatile solids (per cent)	57.7

large increase in volatile acid concentration would not be dependent on the concentration of the volatile acids, but mainly on the concentration and type of cation associated with the alkaline material used for neutralization. Thus, for example, the toxic effect should be different if the acids are neutralized with lime rather than sodium hydroxide, or perhaps ammonium hydroxide. Second, the control of toxic conditions caused by high ion concentration might also be possible through the addition of antagonistic ions if the proper combinations are known.

Procedure

The effect of various salts on acetate-utilizing methane bacteria was studied by adding the salts on a slug basis to a series of 3¼-l digesters containing active acetate fermenting bacteria. Slug feeding the acetate salts simulated the effect of a rapid increase in the volatile acid concentration and subsequent neutralization with alkaline materials. The procedure followed has been described previously (1). A typical analysis of the seed sludge which was acclimated to 2,000 mg/l/day of acetic acid prior to the slug feeding of salts is shown in Table I. The effect of the various salts was evaluated from the rate of acetate utilization as determined by gas production and analysis. The salts studied were the chloride and acetate salts of calcium, magnesium, sodium, potassium, and ammonium. The cations chosen are ones found commonly in relatively high concentrations in sewage sludge and some concentrated industrial wastes. These cations are also associated with common alkaline materials which might be used for neutralization of excess volatile acids.

The fermentation of most of the acetate salts used can be represented essentially by the following equations:

$$CH_3COONa + H_2O \longrightarrow NaHCO_3 + CH_4 \quad (1)$$

$$CH_3COOK + H_2O \longrightarrow KHCO_3 + CH_4 \quad (2)$$

$$CH_3COONH_4 + H_2O \longrightarrow NH_4HCO_3 + CH_4 \quad (3)$$

$$\tfrac{1}{2}(CH_3COO)_2Mg + H_2O \longrightarrow \tfrac{1}{2}Mg(HCO_3)_2 + CH_4 \quad (4)$$

The fermentation of one equivalent of each of these salts, then, results essentially in the production of one mole of methane and one equivalent of the bicarbonate salt. The four bicarbonate salts shown are quite soluble and when produced will cause an increase in pH.

The fermentation of one equivalent of calcium acetate would also result in the production of one equivalent of calcium bicarbonate. However, calcium bicarbonate is relatively insoluble and precipitates from solution as calcium carbonate. This can be represented as follows:

Fermentation:

$$\tfrac{1}{2}(CH_3COO)_2Ca + H_2O \longrightarrow \tfrac{1}{2}Ca(HCO_3)_2 + CH_4 \quad (5)$$

Precipitation:

$$\tfrac{1}{2}Ca(HCO_3)_2 \longrightarrow \tfrac{1}{2}CaCO_3 + \tfrac{1}{2}CO_2 + H_2O \quad (6)$$

Net:

$$\tfrac{1}{2}(CH_3COO)_2Ca \longrightarrow \tfrac{1}{2}CaCO_3 + \tfrac{1}{2}CO_2 + CH_4 \quad (7)$$

The precipitation of calcium carbonate as the fermentation proceeds has the effect of decreasing the calcium concentration in solution, thus decreasing any toxic action which might have been caused by the initial addition of a soluble calcium salt. Fortunately, calcium bicarbonate is not completely insoluble, and a sufficient concentration will normally remain in solution to maintain a pH of about 6.8 to 7.0 in the presence of a normal digestion atmosphere containing 30 to 40 per cent carbon dioxide.

Results

Effect of Various Chlorides

The effect of five chloride salts on the rate of acetate utilization was determined by adding each salt to a digester in an equivalent concentration of 8,300 mg/l as chlorides. An acetate substrate containing 2,000 mg/l as acetic acid and composed of an equal equivalent mixture of the acetates of each of the five cations tested was also added to each digester. A mixture of the acetates was used to maintain identical conditions in all units so that the relative toxicity from the chloride salts alone could be determined.

TABLE II.—Rate of Acetate Utilization and Sludge pH with Addition of 8,300 mg/l Chlorides

Chloride Added	Rate of Acetate Utilization (g/l/day)			Sludge pH	
	Initial	Maximum	Day of Max	Initial	Final
NaCl	0.10	0.32	4	6.80	7.35
KCl	0.10	0.40	3	6.75	7.35
NH_4Cl	0.04	0.16	8	6.80	7.40
$MgCl_2$	0.84	1.20	1	6.80	7.10
$CaCl_2$	1.06	1.44	1	6.75	6.65

The effect on acetate utilization, shown in Figure 1, was quite different with the various salts. Those of the two chemically similar divalent cations, calcium and magnesium, were the least toxic and produced similar results. Salts of the two monovalent and chemically similar cations, sodium and potassium, also produced similar effects, but were appreciably more toxic than salts of calcium or magnesium. The most toxic salt of all was ammonium chloride. A tabulation of the initial and maximum rates of acetate utilization is listed in Table II along with pH measurements taken before addition of the salts and after the acetate

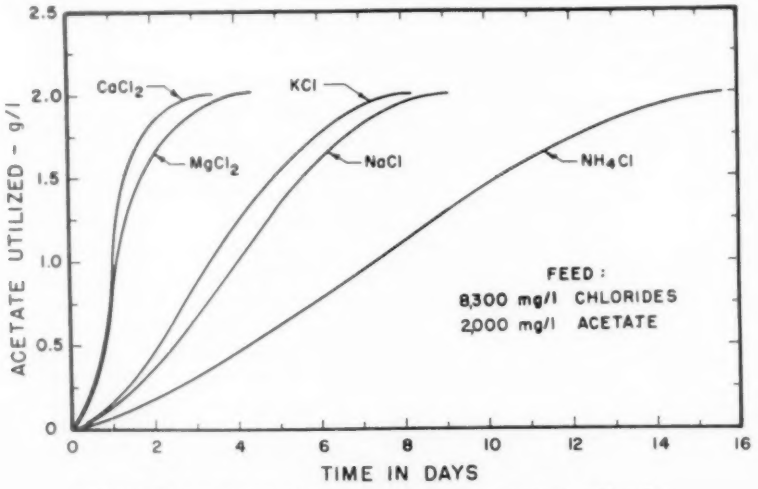


FIGURE 1.—Effect of various chlorides on acetate utilization.

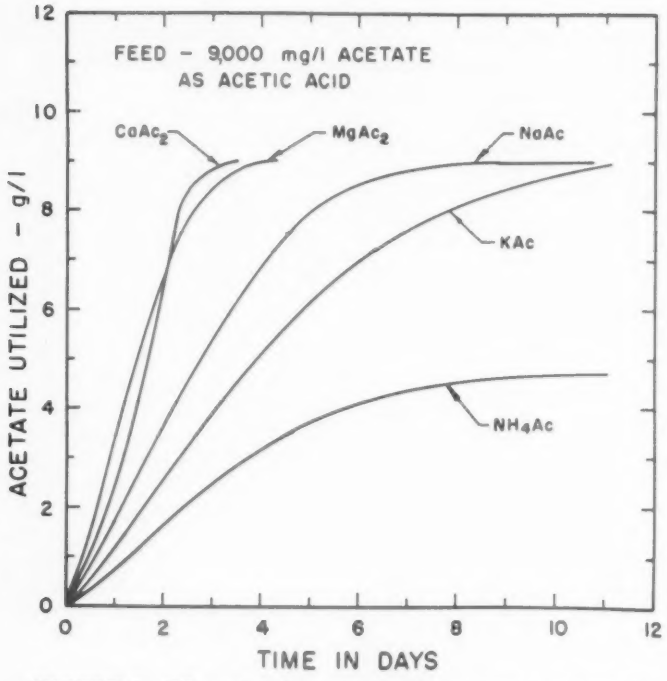


FIGURE 2.—Effect of various acetate salts on acetate utilization.

added was completely utilized. The increase in rates of acetate utilization with time over the initial values indicates that some acclimation to the toxic effect of the salts took place in all units. The lower pH at the end of the run in the unit fed calcium chloride was due to precipitation of the bicarbonate buffer by the calcium.

TABLE III.—Rate of Acetate Utilization and Sludge pH with Addition of Various Acetates

Acetate Added (mg/l as acetic acid)	Rate of Acetate Utilization (g/l/day)			Sludge pH	
	Initial	Maximum	Day of Max	Initial	Final
NaAc*	1.85	1.92	2	6.80	8.10
KAc*	1.40	1.40	1	6.80	8.20
NH_4Ac*	0.85	0.85	1	6.80	7.85
$MgAc_2$*	3.50	3.50	1	6.80	7.95
$CaAc_2$*	2.80	4.08	3	6.80	7.10
NaAc†	0.00	0.55	36	6.75	8.35
KAc†	0.00	0.25	20	6.80	8.35
NH_4Ac†	0.30	0.33	4	6.75	7.80
$MgAc_2$†	1.30	1.67	2	6.80	7.60
$CaAc_2$†	1.30	3.15	7	6.75	7.10

* 9,000 mg/l.
† 16,000 mg/l.

Effect of Various Acetates

Various acetate salts were added to different digestion units in concentrations of 9,000 and 16,000 mg/l as acetic acid. Prior to addition of these salts the sludge seed was acclimated to acetic acid and an equal equivalent mixture of all five of the acetates used in this run. Thus, prior to the slug feeding each digester contained a small but approximately equal concentration of each of the cations. The same relative toxicity of the various cations was obtained with 9,000 mg/l of the acetate salts as was obtained with the chloride salts (Figure 2). The ammonium salt again was the most toxic, and in this

case the unit completely died after the acetate feed was only half utilized.

With 16,000 mg/l of acetate, a much greater difference was found with the various salts as shown in Figure 3 and Table III. The rate of utilization with ammonium acetate was initially greater than with sodium or potassium. However, similar to the feeding of 9,000 mg/l of ammonium acetate, all gas production stopped in this digester after about 3 g/l of acetate had been decomposed. These results indicate a different type of toxicity with ammonium than with the other cations, as methane organisms apparently adapted quite well to the toxicity of the other cations, but with time ammonium became more toxic.

Although the rate of utilization in the calcium- and magnesium-fed digesters was the same initially, the rate increased rapidly thereafter in the calcium-fed digester but decreased in the magnesium-fed unit. This is clearly seen in Figure 4, showing the rate of acetate utilization in three of the digesters as determined from the same data used to construct Figure 3. The rapid increase in rate when calcium acetate was fed was due to precipitation of calcium from solution as the acetate was decomposed and the insoluble calcium carbonate formed. With the magnesium-fed unit this was not the case, and the decrease in rate was probably due to the accumulation of the bicarbonate end product of acetate decomposition, or perhaps due to the resulting increase in pH. A similar slowing down was apparent in the sodium acetate-fed unit. The formation of the bicarbonate end product may also have been the result of the stoppage in the potassium unit, which occurred before acetate utilization was complete. The large difference in toxic effect with the different salts indicates the toxicity of the volatile acid, acetic acid, depends chiefly on the cation associated with the acetate salt.

Effect of Different Calcium Salts

Calcium and magnesium salts were found to be the least toxic to methane fermentation. A comparison of the ef-

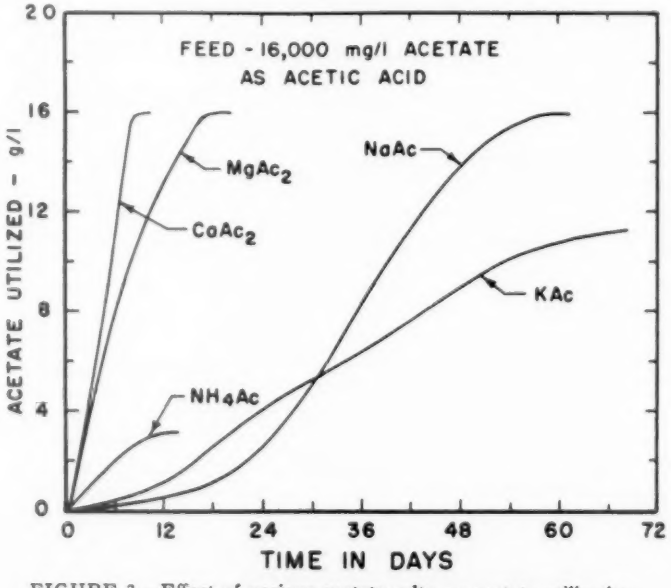


FIGURE 3.—Effect of various acetate salts on acetate utilization.

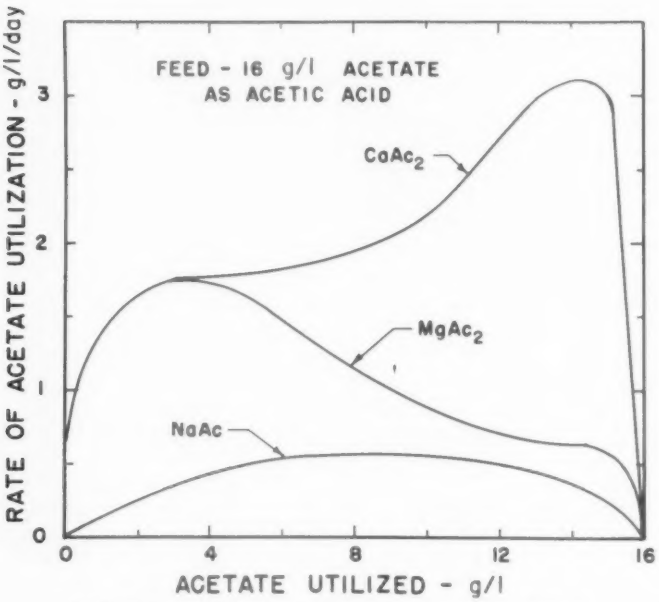


FIGURE 4.—Rate of utilization of various acetate salts.

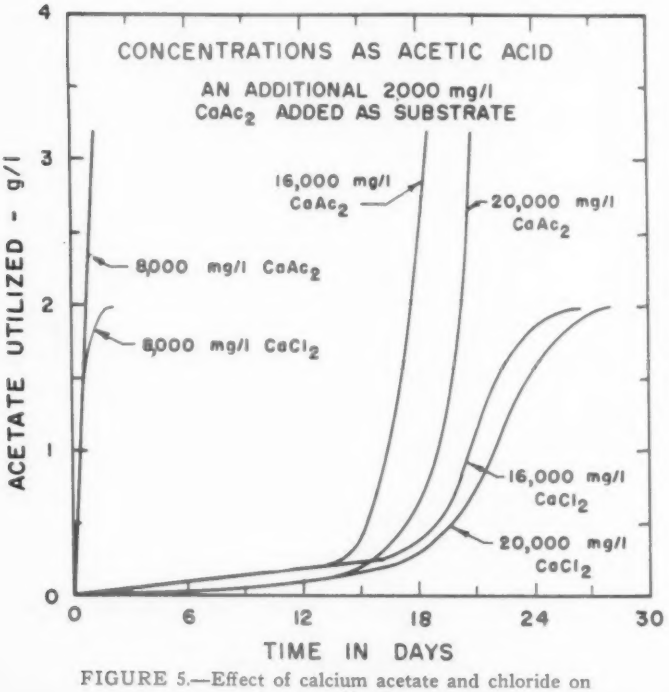


FIGURE 5.—Effect of calcium acetate and chloride on acetate utilization.

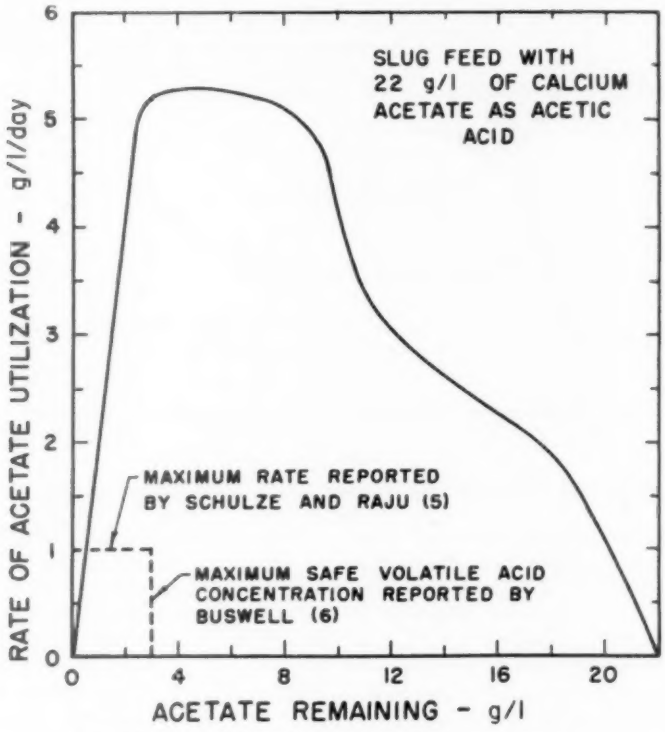


FIGURE 6.—Rate of utilization of calcium acetate.

fect of equivalent concentrations of the chloride and acetate salts of calcium shown in Figure 5 indicates there is relatively little difference between the toxic effect of the chloride and the acetate salts. The relatively low toxicity of calcium salts is indicated by the slightly lower initial rate of acetate utilization (2.38 g/l/day) obtained with 10,000 mg/l as acetic acid (8,000 mg/l salt plus 2,000 mg/l $CaAc_2$ substrate) of either calcium chloride or calcium acetate compared with the rate in the control digester fed 2,000 mg/l of calcium acetate (3.44 g/l/day).

The results from the addition of 22,000 mg/l of calcium acetate are particularly significant and are represented in Figure 6. Here, a plot of rate of utilization is shown against the concentration of acetate as acetic acid remaining in solution. Once acclimated to the calcium acetate salt, utilization proceeded at rates of 1 g/l/day in the presence of 20,000 mg/l of acetate as acetic acid, 2 g/l/day in the presence of 18,000 mg/l. The maximum rate obtained was 5 g/l/day. These rates are as high and higher than maximum rates for acetate utilization reported in the past (5) and were obtained at volatile acid concentrations much above the 2,000 to 3,000 mg/l often considered to be the maximum allowable concentration (6).

Salt Antagonism

The possibility that salt antagonism may be an important phenomenon in acetate fermentation was suggested by the low rates of acetate utilization obtained previously (1) compared with the higher rates of acetate utilization obtained with relatively high sodium

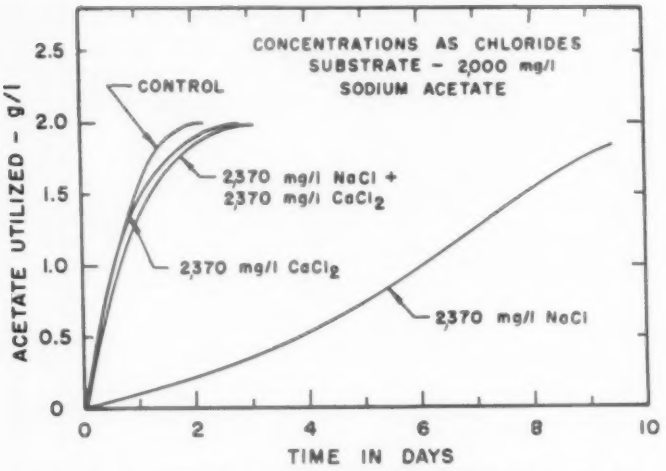


FIGURE 7.—Antagonism between sodium and calcium chloride.

concentrations (Figures 1 and 2). This was suspected as the later high rates were obtained in the presence of small concentrations of calcium, magnesium, ammonium, and potassium ions, added to the seed sludge during acclimation, while the former low rates were obtained without these cation additions. This was confirmed as shown in Figure 7 indicating the antagonism of calcium to the toxic action of sodium when both were added as the chloride salts. Here, a substrate of 2,000 mg/l of sodium acetate as acetic acid was added to each unit. The addition of only 2,370 mg/l of sodium chloride as chlorides caused a significant decrease in activity compared to the control. This

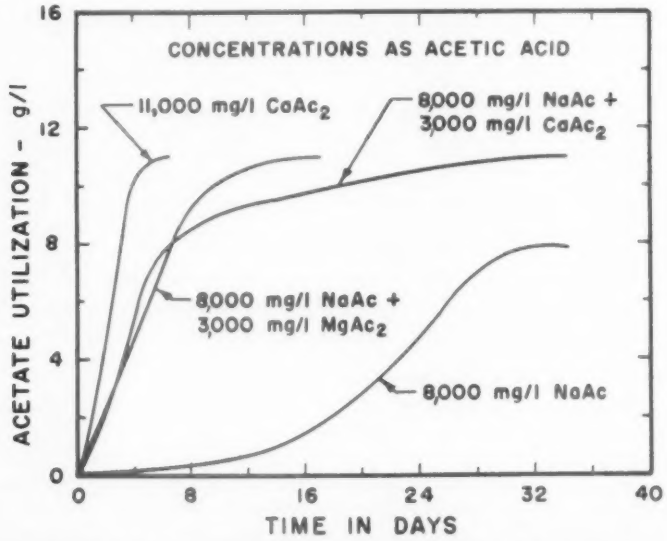


FIGURE 8.—Antagonism of sodium by calcium and magnesium.

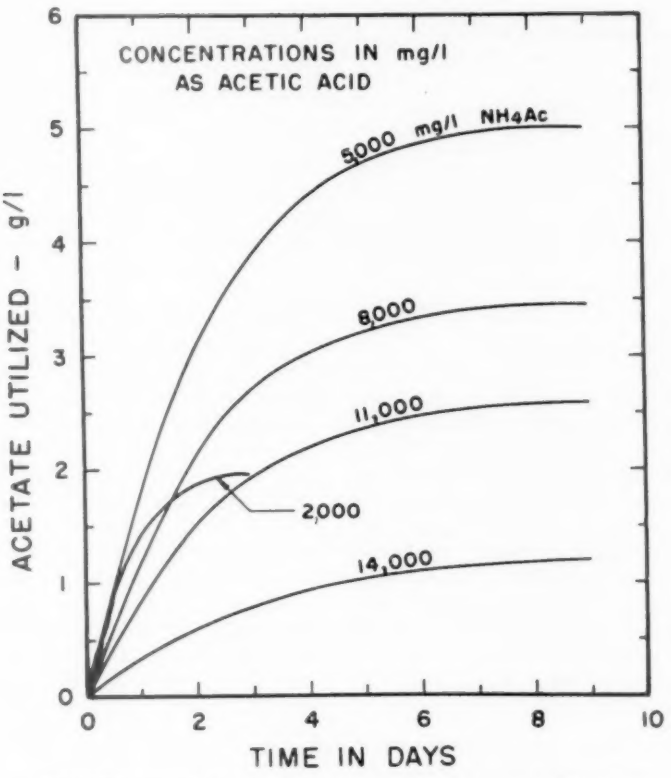


FIGURE 9.—Effect of ammonium acetate on acetate utilization.

toxicity, however, was almost completely eliminated by the addition of 2,370 mg/l of calcium chloride as chlorides.

The antagonism of calcium to the toxic action of sodium when both were added as the acetate salt can be seen in Figure 8. The antagonism of magnesium to sodium is also shown and is almost identical to that obtained with calcium. These results are particularly significant as they show an increase in the acetate concentration to 8,000 mg/l as acetic acid was very toxic when added as the sodium salt. However, this toxicity was almost completely eliminated by increasing the total acetate concentration to 11,000 mg/l by the addition of 3,000 mg/l of either calcium or magnesium acetate. This is, therefore, further proof that the toxicity often noted following a rise in volatile acid concentration and subsequent neutralization with alkaline materials is not the result of the high volatile acid concentration, but is caused by the particular cations associated with the neutralized volatile acid salts.

Differences are noted in the curves for acetate utilization (Figure 8) obtained when calcium was added as the antagonistic ion and when magnesium was added. With magnesium, the rate of utilization was essentially constant until food became limiting after about 9 g/l of acetate had been decomposed. With calcium, a break in the rate came after about 7 g/l had been utilized and then a constant, but much lower, rate

TABLE IV. Effect of Various Ammonium Acetate Additions on Acetate Utilization and Sludge pH

NH_4Ac Added (mg/l as acetic acid)	Acetate Utilization		Sludge pH	
	Initial Rate (g/l/day)	Total Utilized (mg/l)	Initial	Final
2,000	2.00	2,000	7.00	7.55
5,000	2.00	5,000	7.00	7.90
8,000	1.10	3,450	7.00	7.90
11,000	0.85	2,590	7.00	7.70
14,000	0.35	1,200	7.00	7.60

of utilization was obtained for about 24 days. This indicates the effect obtained after sufficient bicarbonate had formed from acetate decomposition to drive the majority of the antagonistic calcium ions from solution in accordance with Equation 6. Without the antagonistic ions present, the rate diminished markedly. Since magnesium bicarbonate is quite soluble, this effect was not observed with the magnesium salts.

Ammonium Toxicity

Ammonium bicarbonate is produced under anaerobic conditions as an end product from the biological decomposition of proteinaceous materials. Normally this compound is beneficial as it acts as a natural buffer resisting a drop in pH from excessive volatile acid accumulation. However, the high ammonium bicarbonate production resulting from digestion of high protein-containing wastes or heavily concentrated sludges may create ammonium ion toxicity. This toxicity appeared somewhat different than that produced by the other four cations studied as shown in Figures 2 and 3. Because of the importance of this ion in digestion, a further understanding of the nature of ammonium ion toxicity is desirable.

The effect of various concentrations of ammonium acetate when added on a slug basis is shown in Figure 9. The initial rate of utilization with the addition of 5,000 mg/l of ammonium acetate as acetic acid was the same as that of the control (2,000 mg/l NH_4Ae) indicating no toxicity at this concentration. The entire feed was utilized in this unit in about 8 days. With higher concentrations, however, the initial rates were below that of the control, and with time the rates of decomposition decreased further until after 9 days all activity ceased in these units, before acetate utilization was complete. There was no increase in activity after an additional 30 days, indicating no acclimation to the toxic effects. A summary of the initial rates of utilization, pH, and acetate utilization for each unit is given in Table IV.

As the ammonium acetate was utilized in each unit, the ammonium bicarbonate end product was formed and the pH increased. From the results, it appeared that the final toxicity was related to ammonium concentration and pH. Thus, the higher the ammonium ion concentration, the lower the pH at which the unit died. The concentration of free ammonia gas in solution is also related to the ammonium ion concentration and pH as shown by the following equilibrium:

$$\underset{\text{Free Ammonia}}{NH_3} + H_2O \rightleftarrows \underset{\text{Ammonium Ion}}{NH_4^+} + OH^- \quad (8)$$

The constants for this equilibrium as well as for water at 35°C are as follows (7):

$$\frac{(NH_4^+)(OH^-)}{(NH_3)(H_2O)} = 1.85 \times 10^{-5} \quad (9)$$

$$\frac{(H^+)(OH^-)}{(H_2O)} = 2.09 \times 10^{-14} \quad (10)$$

Combining:

$$(NH_3) = 1.13 \times 10^{-9} \frac{(NH_4^+)}{(H^+)} \quad (11)$$

Thus, the lower the pH, the higher the ammonium ion concentration re-

quired to produce a given free ammonia concentration.

The free ammonia in solution in the digesters at the start and end of the run was calculated for each unit, using the above equilibrium values and assuming ideal conditions. The results are shown in Table V and indicate that when the free ammonia concentration exceeded about 150 mg/l, the units died.

TABLE V.—Calculated Free Ammonia Concentration in Ammonium Acetate-Fed Digesters

NH_4Ac Added (mg/l as acetic acid)	Free NH_3 Concentration (mg/l as N)		Remarks
	At Start	Final	
2,000	12	43	—
5,000	20	158	Very slow at end
8,000	28	221	Died
11,000	36	180	Died
14,000	44	174	Died

Acetate, chloride, and bicarbonate ammonium salts were then added to different digesters in equivalent concentrations of 4,000 mg/l as acetic acid, along with an additional 2,000 mg/l of ammonium acetate as feed. The addition of the bicarbonate resulted in a much higher pH from the start of digestion than obtained by the addition of the acetate or chloride salts. The effect of this high pH, shown in Figure 10, was a marked decrease in the initial rate of utilization, death of the unit after about 10 days, and utilization of only slightly more than 1,000 mg/l of the acetate fed. The ammonium acetate- and ammonium chloride-fed units started at much higher initial rates. Acetate utilization was complete in the chloride-fed unit after about 8 days. The ammonium acetate-fed unit, however, died before 4 of the 6 g/l of acetate feed had been utilized. At this point the pH had increased to 7.90 due to the production of the ammonium bicarbonate end product. The calculated free ammonia concentration in these units shown in

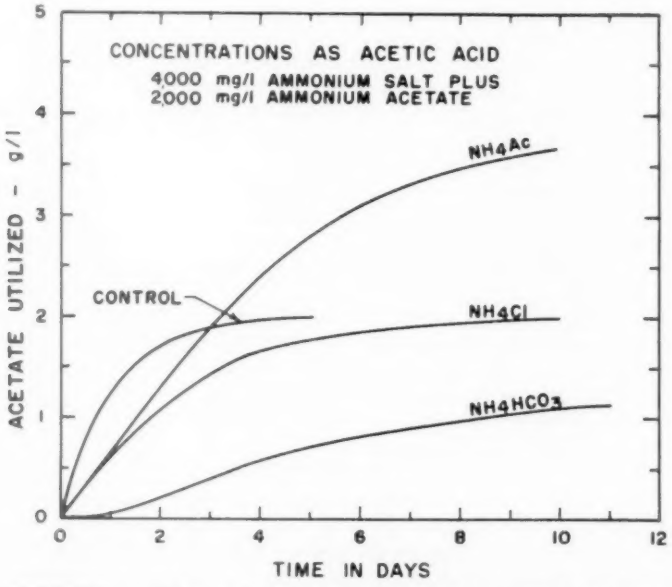


FIGURE 10.—Effect of various ammonium salts on acetate utilization.

TABLE VI.—Calculated Free Ammonia Concentration and Sludge pH in Digester Fed Various Salts

Salt Added (mg/l as acetic acid)	Sludge pH		Free NH_3 Concentration (mg/l as N)		Remarks
	Initial	Final	Initial	Final	
Control	7.0	7.65	12	54	—
4,000 mg/l NH_4Ac	7.5	7.90	23	180	Died
4,000 mg/l NH_4Cl	7.0	7.60	23	91	—
4,000 mg/l NH_4HCO_3	7.5	7.85	72	161	Died
10,000 mg/l NH_4Ac	7.0	7.60	33	132	Died
10,000 mg/l NH_4Ac +4,000 mg/l $MgAc_2$	7.0	7.65	33	149	Died
10,000 mg/l NH_4Ac +4,000 mg/l $CaAc_2$	7.0	7.60	33	132	Died

Table VI again indicates that when the free ammonia concentration exceeded about 150 mg/l the units died.

The effect of pH and ammonia ion concentration on toxicity was then determined by holding the pH constant in one unit, allowing it to increase in two other units, and observing the effect of the pH control on the toxicity produced. This pH control was performed by adding 10,000 mg/l of ammonium acetate as acetic acid to all three units, and then adding an additional 4,000 mg/l of calcium acetate to one of the units and 4,000 mg/l of magnesium acetate to another of the units. The calcium in the one unit precipitated the bicarbonates as they were formed in accordance with Equation 6 and thus prevented the pH from rising above about 7.0 until the calcium all precipitated from solution. The magnesium was added to the second unit to indicate any antagonistic effects which might be produced since magnesium is chemically similar to calcium in this respect. In the magnesium-fed unit, however, the pH would rise with acetate utilization as it would in the unit fed ammonium acetate alone.

The results of these feedings are shown in Figure 11. Magnesium and calcium both appeared to be somewhat antagonistic to the ammonium toxicity. The units fed a combination of magnesium and ammonium acetate, and ammonium acetate alone, quickly died. On the other hand, the rate of acetate utilization in the unit to which calcium acetate was added remained constant until nearly 6 g/l of acetate was utilized. At this point, the calcium was apparently driven from solution, the pH increased, and the unit died. The computed free ammonia concentrations shown in Table VI indicate that death occurred with a concentration above 130 mg/l.

From these results it appears the ammonium ion is toxic in two ways. Initially, when added at a low pH of about 7.0 the ammonium ion produces a toxicity similar in nature to that produced by other ions in solution. Thus, as shown in Figure 9, an increasing ammonium ion concentration results in a decrease in the initial rate of acetate utilization. As the pH increases, however, the second effect comes into play and appears to be related to an increase of free ammonia in solution. This second effect is quite a toxic one and results in the complete stoppage of all activity.

Slow Increase in Salt Concentration

The previous studies were conducted to determine the effect of a sudden increase in the concentration of the various salts. In almost all instances there was acclimation to the toxic salts after

a period of time. This same acclimation should also be obtained if the concentration of salts is increased gradually over a period of time rather than adding on a slug basis. This possibility was studied by seeding a series of the ¾-l digesters with digested sludge and adding diluted acetic acid on a daily feed basis, while operating the digesters on a 30-day detention time. The digester contents were mixed manually after each feeding and before sludge withdrawal. The four cations (sodium, ammonium, calcium, and magnesium) were added daily as the acetate salts along with the acetic acid to four different digesters. This daily feeding resulted in a gradual buildup of each cation in the digester. A fifth digester was fed an equal equivalent mixture of the four cations to determine if higher salt concentrations could be tolerated with a combination of cations.

The ratio of acetate salt to acetic acid fed each day was usually 1 : 1 on an equivalent basis. A summary of the composition of the daily feeds is shown in Table VII. Figure 12 shows the cumulative gas production in liters with time after the start. The cation concentration in the digestion units is also plotted as an abscissa and was computed from the quantity added, minus that withdrawn each day after thoroughly mixing the digester contents.

TABLE VII.—Composition of Daily Feed to Digesters

Day	Composition of Feed (mg/l as acetic acid)	
	Acetic Acid	Acetate Salt
1, 2, 4, 24	0	0
0, 5, 47, 48	1,333	0
6	2,000	0
7 to 13, 16, 20, 25	1,000	1,000
3, 14, 15, 17, 18, 19, 21, 22, 23, 26 to 46, 49 to 54	1,333	1,333

As shown in Figure 12 the ammonium ion was the most toxic and the gas production began to decrease below the theoretical value when the salt

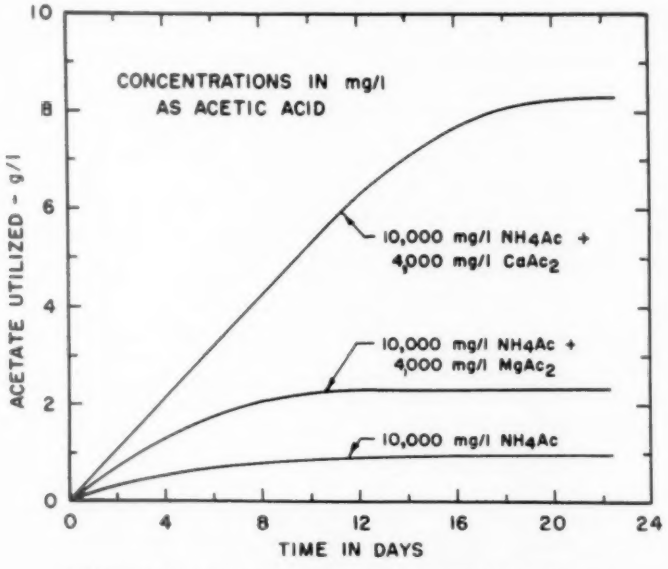


FIGURE 11.—Effect of calcium and magnesium salts on ammonia toxicity.

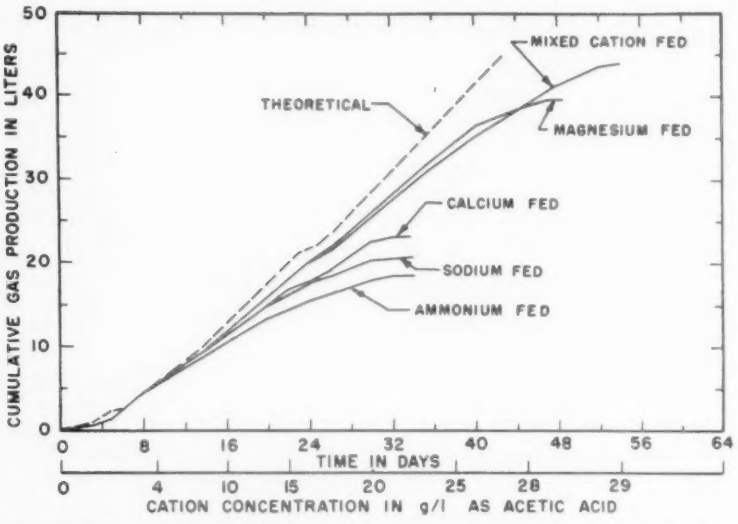


FIGURE 12.—Effect of daily feeding of various cations on acetate utilization.

concentration was just over 4,000 mg/l as acetic acid. The pH, free ammonia concentration, and gas production are shown in Figure 13 for this unit. The pH began to decrease when the free ammonia concentration exceeded about 90 mg/l, and gas production diminished markedly when the free ammonia concentration reached about 140 mg/l. The free ammonia concentration then remained fairly constant, for as the ammonium ion concentration increased, the pH decreased a proportional amount.

Sodium was the next most toxic ion. Significant decrease was obtained when the cation concentration was almost 10,000 mg/l as acetic acid. Calcium,

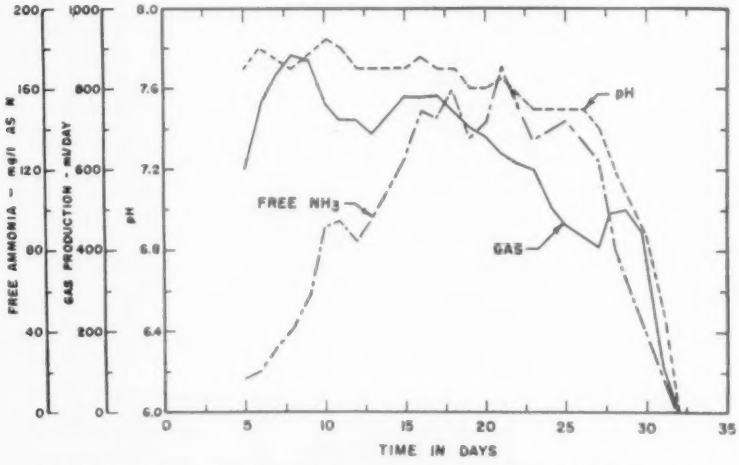


FIGURE 13.—Daily changes in pH, gas production, and free ammonia concentration in ammonia-fed digester.

although much less toxic in the slug-feeding studies, appeared almost as detrimental as sodium with daily feedings. This, however, was not due to salt toxicity, but was due to a lack of buffer capacity and a resulting drop in pH after daily feedings of acetic acid. This lack of buffer capacity was related to the relative insolubility of calcium bicarbonate which precipitated from solution as calcium carbonate. Although sufficient calcium carbonate was present for neutralization, this insoluble salt reacted very slowly and neutralization was incomplete even after a half hour of mixing. The low pH which resulted after feeding of acetic acid finally resulted in the death of this unit.

This problem was not present with magnesium, and acetate utilization proceeded quite well with salt concentrations up to 25,000 mg/l as acetic acid. With salt concentrations above 25,000 mg/l, however, acetate decomposition decreased rapidly, and all activity stopped by the 48th day of operation.

Results similar to those obtained with magnesium were obtained with the mixed cation feed. With this system, no doubt, most of the calcium added was precipitated from solution as calcium carbonate and the actual ionic concentration present in solution was reduced. When salt toxicity became significant in this digester, the concentration of ammonium and sodium ions each were about the same as present in the single cation-fed digesters at the point of toxicity. Because of the high total salt concentration, it is difficult to determine if the action of a single ion or of the combination of ions was actually effective in the final death of this unit.

This run indicated that the same relative order of toxicity by the various cations was obtained when the cations were increased gradually in concentration as when added on a slug basis. In general, however, the concentration could be much higher if added gradually before toxicity resulted. Thus, a sodium concentration as high as 10,000 mg/l as acetic acid or a magnesium concentration as high as 25,000 mg/l as acetic acid, could be tolerated with normal rates of digestion. These concentrations proved quite toxic when added on a slug basis.

Discussion

The volatile acids analysis has been used successfully in the past to determine abnormal or unbalanced digestion conditions. A rapid increase in volatile acids indicates the methane-producing organisms are not keeping pace with the volatile acids production. The test, however, does not furnish the reason for the unbalance which must be known for the proper application of corrective measures. Buswell (6) and Schlenz (8) both believed the volatile acids were toxic regardless of pH maintained and any corrective measures must decrease the concentration of these acids before digestion could proceed. Therefore, they proposed dilution of the digesting mixture or a decrease in the rate of feed as the only satisfactory controls. This would be difficult at many digester installations due to insufficient digestion tank capacity or lack of storage space for the excess waste not added to the digester.

In this investigation it was found that any toxicity which may be present at the higher volatile acid concentrations is associated with salt toxicity and dependent for the most part on the cations in solution rather than the volatile acid anions. Thus, a buildup in volatile acids would not be harmful provided they were neutralized with alkalies containing nontoxic cations. Sodium hydroxide, potassium hydroxide, and ammonium hydroxide would not fit this requirement if needed to neutralize volatile acids in excess of about 2,000 mg/l. Lime and magnesium hydroxide, on the other hand, could be used to neutralize volatile acid concentrations as high as 10,000

mg/l with no harmful effect on the methane organisms. Higher concentrations, however, could cause an initial retardation in the organisms, but with a short acclimation period, their activity would again be high. The successful use of lime for this purpose has been reported at many treatment plants which supports this view.

Since magnesium has been found to be as nontoxic as calcium, magnesium hydroxide could be used as successfully as lime to neutralize high concentrations of acids. However, with the restoration of balanced conditions and decomposition of the excess acids, the calcium would precipitate from solution, but magnesium would remain as the more soluble magnesium bicarbonate. The increased bicarbonate concentration from the use of magnesium would result in an increase in pH which could then again slow down the rate of digestion as shown in Figure 4.

The differences obtained when neutralizing volatile acids with different alkalies may partly help to explain the varying results from neutralization reported by many investigators in the past. Another probable reason for some of the past differences may have been due to antagonistic ion effects. Thus, an investigator in a hard water area may find the use of sodium hydroxide for neutralization only slightly, if at all, detrimental to digestion due to the presence of a relatively high concentration of the antagonistic calcium and magnesium ions in the sludge, while an investigator in a soft water area could find this alkaline material extremely toxic.

Perhaps a more important reason for past differences from the use of pH control was due to the inability to determine the initial source of the digester upset. A high volatile acid concentration is initially caused by other unfavorable conditions and is the result of, not the cause of, the unbalance. Unbalanced digestion conditions could be present during digester startup before the slow-growing methane organisms would be able to reach a sufficient population level. Also, unbalanced digestion conditions could result from changes in temperature or from sudden increases in the organic food load. All these temporary unbalanced conditions could be held satisfactorily in check by the use of lime until the methane organisms could reach a satisfactory population level.

However, unbalanced digestion conditions resulting from the addition of toxic materials would be more difficult to handle as they probably would not be relieved by neutralization alone. In this case, dilution may be the only answer. In certain instances, however, such as a slug load of a sodium salt, the toxicity could be avoided by the addition of an antagonistic ion such as calcium or magnesium. The chloride salts could be used quite well for this purpose. The possibility of decreasing the toxicity of many other cations through the use of antagonistic ions also exists, but requires further study.

The toxicity of ammonium is somewhat strange in view of the fact that ammonium bicarbonate is probably the most important natural buffer present in digesters, and results from the breakdown of protein. This toxicity has been noted by other investigators (9) (10). The relatively high concentration of ammonia necessary to produce toxic conditions compared with the lower concentration normally found in digesters, no doubt explains why this ion has caused few problems in the past. It is expected, however, that with recent developments in the digestion of thickened sludges, the higher ammonium concentration which will result may prove to be a problem at times. It appears this toxicity is related to the free ammonia concentration and may be reduced by keeping the pH down around 7.0 by adding hydrochloric acid, or perhaps better, by the addition of a salt such as calcium chloride which would reduce

the pH sufficiently without the danger of decreasing it too far.

The ability of digestion to proceed normally at relatively high ion concentrations when added slowly over a period of time, may explain why little concern was given in the past to the relatively low concentrations of these same ions which can prove toxic when added on a slug basis. Although approximately 4,000 mg/l of sodium ion was found toxic in the acclimation run shown in Figure 12, additional laboratory studies have shown that sodium concentrations as high as 6,500 mg/l could be tolerated, provided the pH was maintained close to 7.0. When the pH approached 8.0, the rate of digestion decreased. Thus, with higher ion concentration, digestion requires closer control.

Summary

1. The cations studied in order of increasing toxicity to the methane-producing organisms based on equivalent concentrations are: (*a*) calcium, (*b*) magnesium, (*c*) sodium, (*d*) potassium, and (*e*) ammonium.

2. These cations are much more toxic if added on a slug-basis than when added slowly over a period of time.

3. Volatile acid concentrations up to 10,000 mg/l can be successfully neutralized with no inhibiting effects with the use of calcium or magnesium hydroxide, but not sodium, potassium, or ammonium hydroxide.

4. Lime is an excellent material for neutralization of volatile acids because of its low toxicity and its ability to precipitate from solution as the volatile acids are fermented.

5. The toxicity due to a slug-loading of up to 3,500 mg/l of sodium ions can be eliminated by the addition of 500 to 1,000 mg/l of either calcium or magnesium ions which act as cation "antagonists."

6. Ammonium ion toxicity appears similar in nature to the toxicity of other ions at low pH, but appears related to the concentration of free ammonia in solution at high pH.

References

1. McCarty, P. L., and McKinney, R. E., "Volatile Acid Toxicity in Anaerobic Digestion." THIS JOURNAL, **33**, 3, 223 (Mar. 1961).
2. Falk, I. S., "The Role of Certain Ions in Bacterial Physiology. A Review (Studies on Salt Action)." *Abstracts of Bacteriol.*, **7**, 33; 87; and 133 (1923).
3. Abelson, P. H., and Aldous, E., "Ion Antagonisms in Microorganisms: Interference of Normal Magnesium Metabolism by Nickel, Cobalt, Cadmium, Zinc, and Manganese." *Jour. Bacteriol.*, **60**, 401 (1950).
4. MacLeod, R. A., and Snell, E. E., "Ion Antagonism in Bacteria as Related to Antimetabolites." *Annals New York Acad. Science*, **52**, 1249 (1949–1950).
5. Schulze, K. L., and Raju, B. N., "Studies on Sludge Digestion and Methane Fermentation. II. Methane Fermentation of Organic Acid." *Sewage and Industrial Wastes*, **30**, 2, 164 (Feb. 1958).
6. Buswell, A. M., "Fundamentals of Anaerobic Treatment of Organic Wastes." *Sewage and Industrial Wastes*, **29**, 6, 717 (June 1957).
7. "Handbook of Chemistry and Physics," 39th Ed., Chemical Rubber Publ. Co., Cleveland, Ohio (1958).
8. Schlenz, H. E., "Important Considerations in Sludge Digestion. Part I.—Practical Aspects." *Sewage Works Jour.*, **19**, 1, 19 (Jan. 1947).
9. Buswell, A. M., Boruff, C. S., and Wiesman, "Anaerobic Stabilization of Milk Waste." *Ind. Engr. Chem.*, **24**, 1423 (1932).
10. Snell, J. R., "Anaerobic Digestion. III. Anaerobic Digestion of Undiluted Human Excreta." *Sewage Works Jour.*, **15**, 4, 679 (July 1943).

ARSENIC ACCUMULATION BY FISH IN LAKES TREATED WITH SODIUM ARSENITE

William W. Ullmann, Robert W. Schaefer, and Wallace W. Sanderson

Sodium arsenite is one of the most effective herbicides for submerged plants (1). Because of its toxicity, its use in potable water has been restricted. In 1956, weed control by sodium arsenite was started in Chautauqua Lake and Findley Lake in New York State. Since then, the herbicide has been applied annually to portions of both lakes. The depletion of residual arsenic and its concentration in weeds and bottom deposits were studied (2). This investigation was to determine the degree of arsenic accumulation in fish from the two lakes. Fish from Cassadaga Lake, which has never received an application of the herbicide, were used as controls. The study was restricted to calico bass, taken from State Conservation Department muskellunge traps.

Results

Five fish from Findley and 10 each from Chautauqua and Cassadaga Lakes were collected in May 1959 prior to spraying. Twenty-one days after the herbicide was applied to Findley Lake and 11 days after it was applied to Chautauqua Lake, 3 fish from Findley Lake and 10 from Chautauqua Lake were collected. (Analysis of more fish from Findley Lake would have been desirable.)

Arsenic concentration in the fillets including skin and in the viscera including bone and scale were determined by neutron activation analysis (3). Table I summarizes the results. Detectable quantities of arsenic were found in the fillets of all fish from Findley Lake, ranging from 0.27 to 0.47 μg/g of fish. Arsenic was detected in the viscera of seven of these fish, the values ranging from 0.10 to 0.78 mg/l. No significant differences in arsenic concentration occurred between fish taken before or after spraying. This was also true of fish from Chautauqua Lake.

The fish from Chautauqua Lake contained less arsenic than those from Findley Lake. Nine of the 20 fish examined contained measurable quantities of arsenic in the fillets ranging from 0.10 to 0.28 μg/g of fish. Viscera of seven contained detectable amounts ranging from 0.10 to 0.29 μg/g. These values were only slightly higher than those obtained in the control fish. Six of the 10 fish from Cassadaga Lake contained from 0.10 to 0.12 μg/g in the viscera and five contained from 0.10 to 0.14 μg/g in the fillets.

Findley Lake

Findley Lake has a surface area of 0.46 sq miles. The water has a pH of 8.5 and an alkalinity of 56 mg/l (4). A dam prevents the discharge of lake water except during periods of high

At the time this paper was prepared William W. Ullmann and Robert W. Schaefer were Senior Sanitary Chemists for the Division of Laboratories and Research, New York State Department of Health, Albany, N. Y. Mr. Ullmann is now in the Laboratory Division, State Department of Health, Hartford, Conn. Mr. Schaefer's address is now Union College, Schenectady, N. Y.

Wallace W. Sanderson is Assistant Director of the Division of Laboratories and Research, New York State Department of Health, Albany, N. Y.

TABLE I.—Arsenic Concentrations in Calico Bass from Findley, Chautauqua, and Cassadaga Lakes

Lake	No. Fish Examined	Date Caught	Type Sample	Arsenic (μg/g net weight)		
				Min	Avg	Max
Findley	5	5/29/59	Viscera	<0.10	0.33	0.78
	5	5/29/59	Fillet	0.27	0.38	0.47
	3	6/19/59	Viscera	0.14	0.56	1.0
	3	6/19/59	Fillet	0.22	0.28	0.31
Chautauqua	10	5/29/59	Viscera	<0.10	<0.10	0.29
	10	5/29/59	Fillet	<0.10	<0.10	0.28
	10	6/19/59	Viscera	<0.10	<0.10	0.14
	10	6/19/59	Fillet	<0.10	<0.10	0.15
Cassadaga	10	5/29/59	Viscera	<0.10	<0.10	0.12
	10	5/29/59	Fillet	<0.10	<0.10	0.14

flow. The water contained 0.06 mg/l of arsenic prior to this year's spraying. Spraying with herbicide during May 17–20, 1958, caused a maximum arsenic concentration of 7.0 mg/l. One week later the arsenic was distributed throughout the lake in a concentration of 1.5 mg/l and persisted in diminishing quantities during the summer. Fall rains caused the lake water to spill over the dam and resulted in a gradual decrease to pre-spray levels by spring. On May 29, 1959, the herbicide was again applied in lower concentrations. This was followed by a more rapid return to pre-spray levels caused by the lower initial concentration and increased spillage of water over the dam during the summer of 1959.

Chautauqua Lake

Chautauqua Lake is about 15 miles long and has a surface area of about 22 sq miles. The water has a pH of 7.1 and an alkalinity of 209 mg/l (4). The lake water is free flowing. Arnold's Bay, the portion of the lake under consideration at this time, had not received an application of the herbicide prior to June 8, 1959. The arsenic concentration in the water before the herbicide was applied was < 0.01 mg/l. On June 8, four and one-half hours after spraying, it was 0.45 mg/l, and after 11 days had decreased to 0.04 mg/l.

Cassadaga Lake

Cassadaga Lake consists of three small lakes connected by channels, and has a total surface area slightly less than that of Findley Lake. The lake water has a pH of 8.9 and an alkalinity of 64 mg/l (4). The lake water had arsenic concentrations from 0.04 to 0.10 mg/l during the year preceding this study. This arsenic in the lake is believed to be due either to naturally-occurring arsenic in the lake bottom or to drainage from land on which arsenicals have been used.

Summary

In none of the fish examined was an amount of arsenic found equal to that present in edible salt water fish (5). The persistence of residual arsenic in Findley Lake is most likely responsible for the arsenic in the fish. Failure to detect differences in arsenic concentrations between fish taken before and after application of the herbicide illustrates that longer contact periods are necessary for a significant accumulation of arsenic in fish under these conditions.

References

1. Surber, E. W., "Control of Aquatic Growths in Impounding Reservoirs." *Jour. Amer. Water Works Assn.*, **42**, 8, 735 (Aug. 1950).

2. Ullmann, W. W., In: (*a*) New York State Department of Health, Division of Laboratories and Research, Albany, Annual Report for 1956, p. 113; (*b*) Annual Report for 1957, p. 91; and (*c*) Annual Report for 1958, p. 109.
3. Ullmann, W. W., "Determination of Arsenic in Fish by Neutron Activation Analysis." Thesis presented to the Department of Chemistry of Union College, Schenectady, N. Y. in partial fulfillment of the requirements for the degree of Master of Science in Chemistry. (Apr. 20, 1960.)
4. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York (1955).
5. Holmes, A. D., and Remington, R., "Arsenic Content of American Cod Liver Oil." *Ind. Eng. Chem.*, **26**, 573 (1934).

STANDARD METHODS CORRECTIONS

The following changes will be incorporated in the second printing of "Standard Methods for the Examination of Water and Wastewater," 11th Edition. These changes will make the first printing current.

1. P. ix, right-hand column of the WPCF committee should list R. D. Pomeroy.

2. P. xiii, Contents. Under "Phenols," change subcaption to read: "Preliminary Distillation Procedure."

3. P. 11, left column, replace the 6th to 3rd lines from the bottom with: "the necessary correction can be made by adding the color developing reagents to distilled water and nulling the photometer with the resulting solution."

4. P. 12, left column, 5th line, delete "a zero blank standard" and substitute, "distilled water," so that line reads, " . . . through distilled water, while . . .".

5. P. 12, left column, next to last line of Sect. 7, insert, "flocculating or" after "any," so that line reads: ". . . any flocculating or filtering procedure and an attend- . . .".

6. P. 66, Sect. 4.1, 2nd line. Change "100" to "50."

7. P. 108, Sect. 3.2, 2nd line; and P. 368, Sect. 3.12, 2nd line. Change "1, 5-diphenylcarbazide" to "1, 5-diphenylcarbohydrazide."

8. P. 147, second paragraph in introduction to "Lead," 3rd to 7th lines. Place period (.) in the 3rd line after "waters" and delete the following phrase, "sewage, and waters containing organic material and trade wastes." In the 6th and 7th lines of the paragraph delete, "the determination of," and, "in polluted waters." Insert after, "lead," remaining in the 6th line, "in sewage and industrial wastewater," so that that paragraph will read:

> "The method outlined below for the determination of lead is applicable to potable waters. An additional colorimetric method for lead in sewage and industrial wastewater is described in Part III, Metals (Heavy), Method F (Lead)."

9. P. 161, Sect. 4.1, the 8th and 4th lines from the bottom of the page. Change "meter" to "needle" in each case.

10. P. 171, Sect. 4.4. Change the last sentence to read: "Lower the collected distillate free of contact with the delivery tube, and continue distillation during the last minute or two to cleanse the condenser."

11. P. 174, Sect. 2.2. Delete "KOH."

12. P. 174, left column, third line in par. 2.3.b, replace the present chemical symbol, "$KNa_4H_4O_6$" with "$KNaC_4H_4O_6$."

13. P. 184, Sect. 4.3. Revise the last sentence to read the same as in "10" above.

14. P. 197, "Phenols." Revise the title to read, "Preliminary Distillation Procedure."

15. P. 205, Sect. 4.2, 3rd line. Change "10" to "25."

16. P. 284, Sect. 3.2, 15th line. Change the quantity, "3.250" to "3.249."

17. P. 397, left column, Sect. 2.1, change "140" to "125." At the end of that sentence (second line of Sect. 2.1) place an *. The corresponding footnote should read: "* American Instrument Co., Cat. No. 5-226 or equal."

In the 4th line of Sect. 2.2 change the single "*" to a double "**" and make a corresponding change in the footnote that refers to Otto Greiner Co.

18. P. 503, third column from right, the first line in the 6th group of 5 lines, change the "22" to "33."

16. INTERMITTENT SAND FILTERS

Intermittent sand filters, like trickling filters, depend on biological activity to remove a large portion of the organic matter in sewage and convert what remains to a more stable condition. Unlike the trickling filter, the intermittent sand filter strains out and retains on or near its surface most of the suspended solids carried over from the primary treatment processes.

No treatment process known today can produce an effluent superior in quality. With normal rates of application of effluent from separate sedimentation tanks or Imhoff tanks, removals of 95 per cent of the BOD and suspended solids are to be expected. Even when loaded with septic tank effluent, removals of 90 per cent of the BOD and as high as 95 per cent of the suspended solids are common. In some circumstances where an extremely high quality effluent is required, they are used for polishing effluents from secondary processes such as trickling filters or activated sludge.

16.1 FUNDAMENTALS OF PROCESS

When settled sewage is applied to a bed of clean, well-drained sand, the liquid portion will percolate through voids between the sand grains leaving a residue on each sand particle. Most of the solids will be strained out on the surface of the sand. As the liquid drains through the bed, it is replaced by air. This environment encourages the growth and activity of certain microorganisms, mostly bacteria which are present in the sewage. These bacteria quickly become established in this favorable environment of an ample food supply in the presence of oxygen. In their normal life processes, the organisms convert the organic material to a more stable form. Nitrates will be in the range of 10 to 25 mg/l and some dissolved oxygen will be present.

16.2 DESCRIPTION OF THE PROCESS

The essential features (Figure 16-1) of the process are:

1. A well-drained sand bed.
2. Sand of adequate depth and quality to support the bacteria population essential to the purification process.
3. Intermittent dosing of settled sewage, with large particles of matter removed and reasonably free of oils and heavy greases. This promotes favorable drainage through the sand bed and permits replacement of sewage with oxygen essential for biological activity.
4. Uniform distribution of the settled sewage over the entire surface of the sand bed.
5. Drying of the sand surface and subsequent removal of the solids retained on the surface.
6. Replacing sand which is removed with the solids.

This is Chapter 16 of Operation of Sewage Treatment Plants, *Manual of Practice 11. Serialization of this manual began in the September 1960 issue.*

FIGURE 16-1.—Intermittent sand filters.

16.21 Construction Features

16.211 Number of Beds:—Two or more beds are always required even for the smallest installation so that one may be rested and its surface dried while the other is dosed. In most installations, a third bed is needed to allow enough time for cleaning while the second bed is drying. During rainy weather, drying and cleaning may be delayed so a fourth or standby bed is needed for uniformly good results.

16.212 Shape of Beds:—Beds may be square, rectangular, or circular. Their shape is determined largely by the land area available and the method used for applying sewage to the filter. When rotary distributors are used, the bed must be circular.

16.213 Underdrains:—The area for the sand bed is usually excavated to provide a flat slope toward the underdrains which are surrounded by gravel. The drains are usually spaced about 10 to 20 ft apart and provided with some means of protection from clogging of the joints with sand filtering down through the overlying gravel.

16.214 Gravel and Sand:—Several inches of gravel are laid over the lower layer of gravel and underdrains at varying depths to compensate for the slope of the floor, so that the top surface of the gravel is level. Above this layer is at least 18 in. of the filter sand. Usually the depth of the sand is at least 24 in. Although some beds have as much as 36 in. of sand, very little additional treatment may be expected from the additional depth. The chief advantage of greater depth is the relatively longer period before replacement of the top layer is necessary.

The most important requirements for the sand are freedom from dirt and uniformity of size. Dirt tends to clog the voids between the sand grains. A similar effect may be produced with sand of widely varying sizes. Ideally, perhaps, the sand should be washed, have a uniformity coefficient of about 3 (not higher than 4), and be about 0.3 to 0.5 mm in size. Clean, medium-coarse sand of reasonably uniform size has produced good results in many plants. When sand is replaced on the beds, it should be similar to that remaining on the beds for effective performance.

16.215 Dosing Equipment:—For effective dosing, storage large enough to handle the dosage volume must be provided and the stored volume must be discharged in a short period—usually 10 to 20 min or less.

Automatic alternating siphons which

discharge at prescribed water elevations are frequently used to deliver the settled sewage through the distributors to the beds. These devices are installed in dosing tanks and are so arranged that the several beds are dosed alternately on a selected rotation cycle. Alternating pumps governed by water level elevations in the wet well are also used for this purpose.

16.216 Distributors:—The essential requirement for a distributor is uniformity of distribution over the entire surface of the bed with a minimum of scouring of the sand. This may be accomplished in many ways, but very frequently the facilities do not meet this objective. Wooden troughs, commonly installed 30 years ago, are seldom used today by reason of (*a*) lack of sufficient outlets for good distribution, (*b*) scouring, (*c*) dead areas under the troughs, and (*d*) need for frequent maintenance, reconstruction, and replacement. Multiple outlets from pipeline distributors on partially baffled splash aprons often are furnished in a variety of forms. In recent years, rotary distributors similar to those used for trickling filters have gained increasing favor. Some are actuated by the sewage flow and others are motor driven.

16.3 MANAGEMENT OF SAND FILTERS

Effective management of an intermittent sand filter involves strict observation of the following principles:

1. Dosing must be intermittent and scheduled to provide adequate time for resting between doses;
2. Flow must be distributed uniformly;
3. Daily loading should not exceed reasonable limits;
4. Surface of the sand must be kept free of dirt and weeds and accumulated solids must be removed regularly after drying; and
5. Sand must be replaced before it becomes so shallow that efficiency is lowered.

16.31 Control of Dosage

A schedule should be developed so that each filter in use will be dosed not more than three times per day; twice daily is usually preferable. The depth of flow per dose is regulated by:

1. The volume of sewage stored in the dosing tank or pump wet well before release, and the rate of inflow to the tank or wet well during the dosing period. These volumes may be adjusted by the operator within limits.

2. The desired rate of application per day. These rates may vary from about 1 gpd/sq ft for septic tank effluent to about 10 gpd/sq ft for secondary treatment plant effluent. Normal rates for effluents from Imhoff tanks or plain sedimentation tanks range from about 2 to 4 gpd/sq ft. A rate of 3 gpd/sq ft is equivalent to an application of about 5 in./day. Two doses of 2½ in. per dose would be preferable over either one or three doses for this total application. A depth of 2 to 4 in. per dose is usually considered desirable.

A leaky siphon which permits continual passage of flow rather than storage to the prescribed level should be corrected promptly. Leaks or badly corroded piping should be repaired or replaced at once.

16.32 Uniformity of Distribution

Lack of uniformity of distribution may be caused by:

1. Rotary distributor failing to rotate or partial or complete stoppage of some of the orifices. The orifices require attention at least once daily.

2. Constant flow from dosing siphon causing sewage to dribble from distribution system to small areas near points of discharge.

3. Dosing rate too slow by reason of undersized siphon or pump.

16.33 Care of Sand

16.331 Solids Removal:—After the sand bed has drained and the deposited solids have dried sufficiently to be removed with a rake, the crust should be removed with rake, fork, or shovel. After this has been done, scarifying with a rake or spike-tooth harrow to a depth of an inch or more, but not to exceed about four inches, helps to promote drainage of the next batch of sewage and aids in the desirable circulation of air through the sand bed. Care should be taken to minimize the mixing of accumulated sewage solids with the sand.

16.332 Replacement:—Unless the sand is deeper than necessary, the loss during solids removal should be replaced when about three inches has been removed.

16.333 Protection from Dirt:—Care should be taken to keep dirt from the surrounding embankments from washing or otherwise encroaching upon the sand beds. Suitable walls should be maintained in good condition and the earth sodded if necessary. When solids have been removed from the filter, they sometimes are deposited on the sloping embankments. This is not good practice as some of this material may eventually slide back on the bed.

16.334 Weed Control:—A sand filter supporting vegetation of any type and in any quantity has reduced efficiency. Some obvious control methods are:

1. Reduce propagation by keeping adjacent areas mowed before weeds go to seed,

2. Use weed killers on adjacent areas and on the sand beds, and

3. Use clean sand free of dirt on the filter.

16.335 Control of Odors

Overdosing a filter for prolonged periods may result in the encouragement of odor-producing organisms. Odors may also arise from septic tank effluent or large quantities of grease and fatty materials.

Chlorination of the sewage before spreading it on the filter will greatly reduce odors from septic sewage. The rate of chlorine dosage will vary widely with the condition of the sewage. A dosage of about 10 mg/l has been found effective in the control of odors from septic tank effluent after a few minutes' contact.

17. DISINFECTION AND CHLORINATION

17.1 CHLORINE USES

Chlorine is used for a wide variety of purposes in sewage treatment. Although disinfection has been its major and most important function, its peculiar characteristics make it adaptable to many purposes in wastewater collection and treatment plants. Briefly discussed below are some of its common and more important uses.

17.11 Disinfection

The most important use of chlorine in sewage treatment is to destroy pathogenic and non-pathogenic organisms to prevent nuisances and to protect municipal water supplies, shellfish areas, bathing beaches, and other recreational areas.

17.12 Reduction of Odors

Chlorine will react with hydrogen sulfide to eliminate odors. These odors also are reduced or controlled by the reduction in the number of bacteria which decompose the sewage. Chlorine used to kill bacteria may delay the decomposition until the sewage arrives at the treatment units.

17.13 Reduction of Damage

By using chlorine to delay decomposition and to react with hydrogen sulfide already formed, the production of sulfurous acid may be reduced sufficiently to reduce or eliminate damage to sewer systems and structures. This is particularly significant where temperatures are high and time of travel in the sewer system is unusually long.

17.14 Aid to Treatment

Improvement to regular treatment processes is accomplished in the following ways:

1. Increases removal of BOD. Each mg/l of chlorine added to raw sewage or clarified effluent will reduce the BOD by about 2 mg/l.
2. Increases removal of settleable solids.
3. Improves clarification by the chemical precipitation process.
4. Increases grease removal by breaking emulsions, permitting grease to float.
5. Improves clarification by:
   (*a*) Improving settling rate,
   (*b*) Reducing septicity of raw sewage, and
   (*c*) Increasing grease removal.
6. Improves trickling filter operation by reduction or elimination of ponding and control of filter flies (*psychoda alternata*) by removal of breeding grounds in organic material on filter surface.
7. Improves activated sludge treatment by reducing bulking when chlorine is added to return activated sludge and used in cleaning clogged air diffusers.

17.2 FUNDAMENTALS OF CHLORINATION

Chlorine kills bacteria in sewage and thus reduces the normal development of microorganisms. Since the bacterial population is lower, putrefactive reactions are reduced if not eliminated entirely. It is these bacterial putrefac-

tive reactions which result in odors and all other nuisance conditions in sewage.

Sewage, being a complex mixture of organic and inorganic material, contains many substances which will react directly with chlorine. When ammonia is present chloramines are formed. Before the chlorine (or chloramine) can attack and kill bacteria, all other direct chemical reactions must be satisfied.

The chlorine requirement of sewage is the amount of chlorine needed to satisfy direct chemical reactions and to produce a minimum residual of chlorine or chloramine. The chlorine requirement depends on the quantity and kinds of chemical substances present in sewage and their affinity for chlorine, type and condition of sewage, contact time, and temperature. Residual chlorine is the amount of combined chlorine that will react with orthotolidine after a specified contact time.

17.3 DESCRIPTION OF PROCESS

17.31 Type of Chlorination

When sewage has been chlorinated to the extent of producing a residual, that residual will be of the "combined-residual type," that is, it will represent chloramines, since ammonia is always present in sewage. Free residual chlorination, that is, chlorination to produce a free chlorine residual, is never practiced in sewage treatment because of the high amount of chlorine required to produce a free chlorine residual where so much ammonia exists.

17.32 Points of Application

Points of application are based on consideration of both the purpose and the physical layout of the system. Application points include:

17.321 Upsewer Chlorination:—Chlorine is added to sewage before it reaches the treatment plant usually for the purpose of preventing septicity, odors, and sewer corrosion.

17.322 Prechlorination:—Chlorine is added to sewage at the entrance to the treatment plant (or ahead of sedimentation and prior to any other chemicals); usually for the purpose of disinfection and BOD reduction.

17.323 Postchlorination:—Chlorine is added to sewage following treatment by other processes; usually preceding a chlorine contact tank, final sedimentation tank, or long outfall, and usually for the purpose of disinfection.

17.324 Plant Chlorination:—Chlorine is added to sewage during treatment by other processes, the specific point of application being related to the results desired. The purpose of plant chlorination may be for control of odors, corrosion, sludge bulking, digester foaming, filter ponding, filter flies, or sludge thickening.

17.33 Chemical Used

For disinfection and other purposes, the chemical most commonly used is chlorine although hypochlorites may be used, particularly for small locations and special problems.

17.34 Properties and Characteristics of Chlorine

Chlorine is a particularly active chemical produced by the electrolytic decomposition of salt brine. Table 17-1 lists the properties of chlorine.

17.35 Chlorine Containers

For commercial use, chlorine is liquefied under pressure and shipped in 100, 105, or 150 lb cylinders, 2,000 lb (ton) containers (Figure 17-1), multiple unit tank cars, single unit tank

TABLE 17-1.—Chlorine Properties*

Item	Liquid	Gas
Color	Amber	Greenish-yellow
Odor	—	Pungent-irritating
Density, lb/cu (0°C, 39 psi)	91.64	0.2006
Specific gravity (Air = 1.0)	—	2.486†
(Water = 1.0)	1.46	—
Vapor pressure,‡ mm (0°C, 32°F)	39	—
(20°C, 68°F)	82	—
(40°C, 104°F)	150	—
Boiling point	−34°C, −29.2°F	—
Solubility,§ g/100 ml (10°C, 50°F)	—	0.98
(20°C, 68°F)	—	0.716¶
(30°C, 86°F)	—	0.572
(40°C, 104°F)	—	0.46

* At ordinary temperatures, dry chlorine (liquid or gas) will not corrode steel, copper, or other common metals. In the presence of moisture, chlorine is extremely corrosive.

† 1.0 lb of liquid will produce 5 cu ft of gas or one volume of liquid will produce 457 volumes of gas.

‡ This pressure is not affected by volume of liquid, hence chlorine pressure gages are not indicators of amounts of liquid in container.

§ Below 9.6°C (49.3°F), chlorine combines with water to form solid chlorine hydrate (chlorine ice), $Cl_2 \cdot 8H_2O$.

¶ Approximately 17 gal of water are required to dissolve 1.0 lb of chlorine to form saturated solution. For practical purposes, double this value is used.

cars (16, 30, and 55 tons) (Figure 17-2), and tank barges.

Cylinders are of seamless steel with a cylinder valve containing a fusible metal safety plug designed to soften and melt between 158 to 165°F and fitted with a bonnet designed to protect the valve from impact. They are hydrostatically tested at regular intervals. Cylinders are thoroughly cleaned and inspected and valves reconditioned and tested before each filling. Ton containers are steel with ends dished and are equipped with two identical valves without fusible plugs. (Three fusible metal safety plugs are placed in each end of the container.) The valves, protected by a removable steel hood, except when the container is in use, are connected to eductors reaching opposite ends of the tank diameter. When the container is in a horizontal position with valves aligned vertically, chlorine can be withdrawn, either as a gas or liquid.

Tank cars and barges are of welded steel covered by insulation, protected by a light steel jacket. A dome in the center top of the tank contains two valves for liquid and two for gaseous chlorine. A safety valve will relieve pressure under abnormal conditions and an automatic check valve will shut off chlorine flow if a delivery line should break.

High-test hypochlorite is a form of calcium hypochlorite, available in sealed metal containers. Sodium hypochlorite solution containing about 15 per cent

FIGURE 17-1.—Ton containers of chlorine and chlorine feeders.

FIGURE 17-2.—Large chlorine storage facilities.

chlorine may also be used, but neither of the hypochlorites is commonly used unless a source of hypochlorite solution is available from a nearby producer.

17.4 MANAGEMENT OF CHLORINATION

17.41 Handling Chlorine Containers

Cylinders should be stored upright and ton containers cradled horizontally in a cool, dry place, which should be well-ventilated and away from heat sources, walkways, elevators, stairways, and ventilating system intakes. Indoor storage should be above ground and fireproof; outdoor storage should provide protection from direct sun, snow, and debris.

Ton containers require a hoist and lifting clamp for handling; cylinders may be clamped to a balanced hand truck for moving. Never use a lifting magnet, chain, or rope sling. Do not drop or allow chlorine pressure vessels to strike one another with force.

Use containers in the order received and return empty tanks promptly. Make connections with approved fittings only; open valves slowly, one complete counter-clockwise turn, using a wrench no longer than six inches. Test for leaks with ammonia and correct leaks immediately. When scales or chlorine recorder indicates an empty tank, close valves, disconnect tank, test for leaks, and cap container.

17.42 Materials for Handling Chlorine

Dry chlorine gas or liquid, under pressure, is handled in extra heavy black iron, wrought iron, steel pipe, copper tubing, or other metals which will withstand high pressures. Flexible copper tubing connectors (whips) are used to connect chlorine cylinders and ton containers to feeders or manifolds and connections to tank cars.

Dry chlorine gas under low pressure or vacuum may be conveyed in the same materials as pressure gas; also in hard rubber, Uscolite, polyethylene,

and other plastic materials. Moist chlorine is handled in glass, rubber, hard rubber, plastic, silver, and other corrosion-resistant conduits. Chlorine solution is handled in hard rubber, rubber-lined, or saran-lined piping, rubber-lined hose, polyethylene hose, or Uscolite piping.

17.43 Chlorine Container Delivery

Table 17-2 shows how much chlorine gas may be discharged from different containers at various temperatures.

TABLE 17-2. Chlorine Discharge at Various Temperatures

Temp. (°F)	Chlorine Discharge (lb/day)		
	105-lb Cylinders	150-lb Cylinders	Ton Containers
40	6	9	100
50	14	21	240
60	23.7	35.5	385
70	32	47.5	536
80	41.2	62	700

When one container will not discharge enough gas to meet needs, two or more containers may be connected to a manifold. When the desired rate as gas requires the manifolding of an impractical number of containers, liquid chlorine may be delivered to a heated evaporator where it is converted to a gas. Direct heat must never be applied to a chlorine container. Chlorine suppliers or the Chlorine Institute, Inc., can furnish detailed information on chlorine handling.

17.44 Chlorine Feeders

17.441 Types of Feed:—Chlorine may be delivered from a feeder by one of two methods: (*a*) solution feed, commonly practiced, in which the chlorine gas is controlled, metered, introduced into a stream of makeup water, and then conducted as a solution to the point of application; and (*b*) direct feed, sometimes called dry feed, in which the gas is introduced directly through a suitable diffuser at the point of application. This latter method is infrequently used because of operating difficulties and hazards.

17.442 Types of Feeders:—Vacuum-type chlorine feeders meter chlorine gas, convey it through the apparatus under vacuum, and employ an injector into which the gas is drawn to provide solution feed.

In a full-vacuum type feeder, the vacuum governs the operation of the chlorine inlet valve directly, or indirectly, so that the chlorine will not feed unless sufficient vacuum is induced through the apparatus. In a feeder of this type which employs a direct indicating meter, the flow of chlorine is automatically shut off on loss of vacuum, stoppage of discharge line, or loss of operating water pressure.

In the partial-vacuum type feeder, which usually employs a direct indicating meter, opening of the chlorine inlet valve is not vacuum governed and the feeder will not automatically shut off flow of chlorine on loss of operating water pressure, loss of vacuum, or stoppage of injector. During normal operation, chlorine gas is maintained under vacuum.

Pressure-type chlorine feeders are commonly used for direct feed. No safety is afforded and the gas is under pressure during normal operation. The device usually employs a direct indicating meter.

Pulsating-type feeders are similar to partial-vacuum type except the metering device is a volumetric pulsating unit and the rate of chlorine feed must be ascertained by timing the meter pulsations.

17.443 Type of Control:—Chlorine gas feeders are controlled by one of four methods:

1. Manual control equipment is put in operation and shut down, manually,

by the operator and the rate of chlorine feed is established by manual adjustment.

2. Semi-automatic control, or start-stop equipment, feeds automatically with pump operation at rate manually pre-set.

3. Step control, a variation of semi-automatic control, used in multipump installations, in which chlorine feed is automatically synchronized to provide proper dosage for a particular pump or combination of pumps in operation.

4. Program control equipment provides automatic changing of the chlorine feed rate to provide a constant pre-established dosage for all rates of flow.

17.444 Water Requirements:—A small supply, usually less than 1 gpm, of strained, clear water is required for control purposes. In addition, a supply of water is required to operate the injector and produce solution. If strained sewage effluent, high in ammonia content, or high-oxygen-demand river water is utilized for injector operation, sufficient extra chlorine must be added to react with and destroy the ammonia or to react with other high-oxygen-demand substances present. The cost of the extra chlorine makes it feasible to use high quality water for injector operation whenever possible.

17.445 Chlorine Discharge Distribution:—Chlorine gas will discharge continuously from a cylinder at a maximum of 40 to 50 lb/day and from a ton container at 450 lb/day. When the desired rate of feed is above single cylinder or container capacity, multiple containers may be connected to a manifold to provide the desired output. These manifolds are made of materials resistant to dry chlorine gas and are suitably valved to discharge to one or more feeders. When the capacity of multiple containers is exceeded, chlorine evaporators are used.

17.446 Location of Equipment:—The installation and arrangement of gas-feeding equipment must take into consideration: point of application, type of equipment, location of feeders, accessories, location of chlorine containers, evaporator (when used), piping arrangements, heating facilities for feeder and container areas, chlorine handling, and safety.

17.45 Chlorine Required

Many states require 15 min contact time as a minimum; some require 20 min; and one or two require 30 min. About half the states require a residual chlorine of 0.5 mg/l after the minimum contact time.

The chlorine requirement of raw sewage varies with the composition of sewage and its freshness or septicity, all of which are related to time of day, day of week, or season of the year. Chlorine requirements of treated sewage depend on the extent of the treatment. Common values for disinfection are listed in Table 17-3.

TABLE 17-3.—Chlorine Requirements

Type of Sewage		Demand (mg/l)
Raw sewage (fresh to stale)		6–12
(septic)		12–25
Settled sewage (fresh to stale)		5–10
(septic)		12–40
Trickling filter effluent	(normal)	3–5
	(poor)	5–10
Activated sludge effluent	(normal)	2–4
	(poor)	5–8

17.46 Chlorination Capacity

The quantity of chlorine required in any time period depends on the chlorine requirement and quantity of sewage.

Chlorine feeder capacity is rated in terms of lb/day, and may be calculated as follows:

$$\text{lb/day} = \text{dosage (mg/l)} \times \text{max flow (mgd)} \times 8.34$$

17.47 Control of Dosage for Disinfection

Ultimate control rests on the results desired, that is, the bacterial reduction desired. Determination of chlorine requirements according to the current edition of *Standards Methods for the Examination of Water and Wastewater* is the best method of control.

Determination of chlorine residual after plant contact gives confirmatory data on previous choice of dosage, and

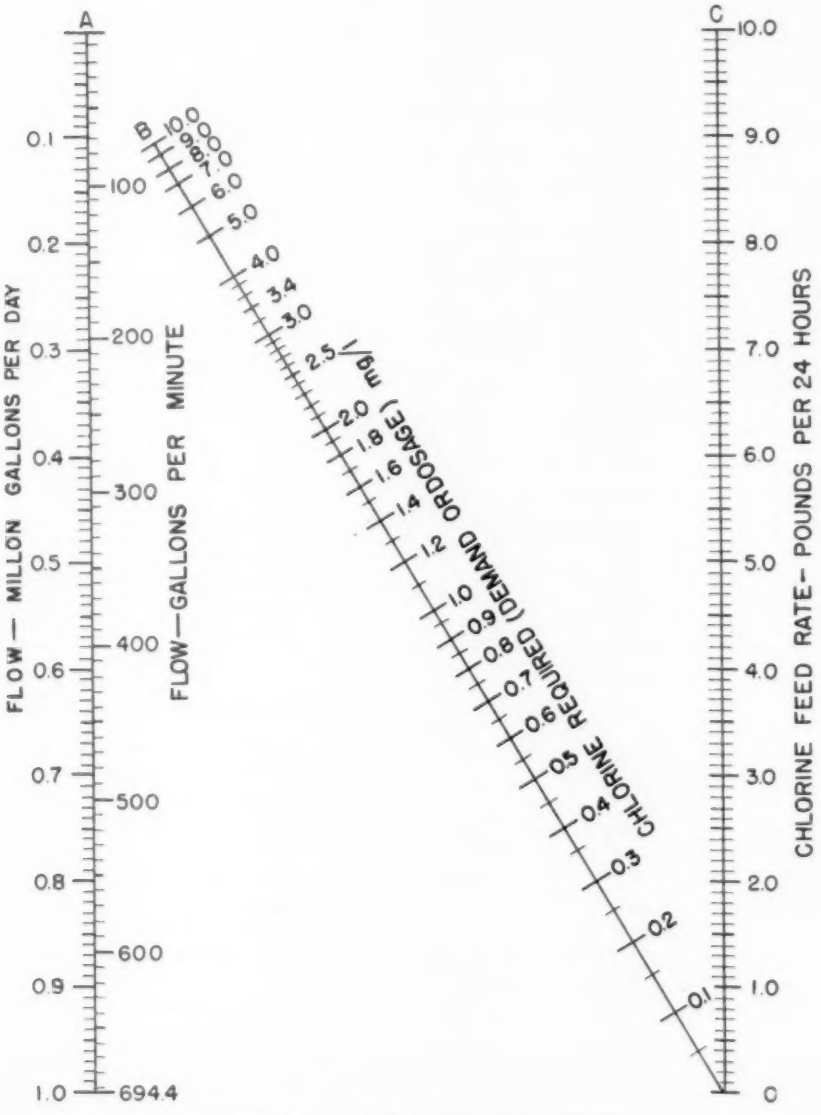


FIGURE 17-3.—Chlorination control nomogram.

may serve to indicate need for readjustment of dosage.

17.48 Feeder Discharge Rate Adjustment

1. Since feed rate is expressed in lb/day, the rate setting on the feeder must be calculated from determination of chlorine required and the flow. The simplest means of making the calculation is by a chlorination control nomogram (Figure 17-3).

To use this nomogram:

(*a*) Lay straight-edge on point on Line *A*, representing flow, and on point on Line *B*, representing chlorine required, and read point on Line *C*, which shows setting for chlorine feeder.

(*b*) For any value in excess of maximum indicated on Scales *A*, *B*, or *C*, introduce proper factor of 10 or multiple thereof.

(*c*) Greatest accuracy will be had when the angle of the straight-edge approaches a right angle with Line *B*. Multiplier of 10 may be applied to aid in accomplishing this objective.

(*d*) If straight-edge does not cross all three scales, introduce necessary factors of 10, 100, etc., and move straight-edge to points where all three scales will be crossed.

2. As pointed out, chlorine requirements vary with the sewage concentration and flow. Adjustment of chlorine feeder rates to meet all of these variations is the ultimate goal of good operation practice. More frequent adjustments are usually required for primary effluents than for secondary effluents.

3. Schedule for adjusting feeder rates:

(*a*) In large plants—at least every hour,

(*b*) In medium-sized plants—every 2 to 4 hr, and

(*c*) In small plants—every 8 hr.

4. Feed settings must be high enough to produce the desired residual for the maximum chlorine requirement expected in the ensuing period.

5. Semi-automatic control of chlorine feeders proportional to flow rates takes the burden of frequent adjustment off the operator.

17.49 Control of Dosage—Other Purposes

Sub-residual chlorination, particularly upsewer, may be sufficient and effective for odor control. Careful control is less important than for disinfection and usually based on observation of conditions resulting from chlorination.

17.491 Feeder Adjustment:—Definite schedules are not essential, except that for odor control in the summer season, higher dosages are necessary.

When hypochlorite is used, a proportioning chemical feeder is required and dosage rates are adjusted according to needs.

17.492 Equipment Maintenance:—

1. Mechanical operation and control of chlorine feeders should be in accord with the manufacturer's instructions.

2. Feeders subject to operating difficulties caused by chlorine hydrate (chlorine ice) should have the water supply warmed to at least 50°F.

3. Leaks from chlorine feed lines call for safety precautions and immediate repair.

4. Preventive maintenance procedures for chlorine feeders are usually set forth in the equipment manufacturer's instruction manual.

17.5 SAFETY ASPECTS

1. Chlorine is a respiratory irritant. Danger exists when chlorine escapes. Serious physiological damage may result from breathing chlorine-contaminated air. (For additional discussion of this topic see *Safety in Wastewater Works*, Manual of Practice No. 1, published by the Federation.)

2. Hold ammonia-moistened cloth near a suspected area to locate a chlorine leak. If chlorine is escaping, a white cloud will form.

3. Keep canister-type gas masks (U. S. Bureau of Mines Approved) readily available outside the area of chlorine storage or use. Canisters do not supply oxygen, but absorb chlorine from the air.

4. A hose mask or air-demand type mask is essential when high concentrations of chlorine (above 1 per cent by volume with air) are present.

5. In handling chlorine, observe these safety factors:

(*a*) Handle all containers as though they were full.

(*b*) Do not tamper with fusible plugs, or alter or repair tanks.

(*c*) Remove valve protection hoods only when containers are in use; do not hoist containers by the hood.

(*d*) Correct leaks at once; repair kits for fixing leaks in both 150-lb and ton containers are available. *Never* apply water to a chlorine leak or leaking container.

(*e*) Place a leaking container so that only gas will escape and move it to an isolated area or immerse it in caustic soda or slurry of hydrated lime.

(*f*) Notify chlorine supplier at once in an emergency.

(*g*) Call a physician in event of accident.

17.6 LABORATORY CONTROLS

Laboratory controls for disinfection consist of tests for residual chlorine and coliform organisms. See Section 6.5 for a discussion of these tests.

18. EFFECTS OF INDUSTRIAL WASTES ON SEWAGE TREATMENT

At many sewage treatment plants, large and small, industrial wastes cause more difficulties in operational control than any other single problem with which the plant operator must deal. There are several reasons for this situation, the most common being the lack of appreciation of the problem by the parties involved due to either limited knowledge or interest.

The design engineer gives full consideration to domestic sewage loadings and flows, but may not be fully aware of or make adequate provision for industrial wastes, although these wastes may contribute a very significant load on the plant. Consequently, the necessary features to handle the waste may not be designed into the plant.

Many times, industry has little appreciation of the problem it is creating. There are many waste prevention measures which can be adopted by industry to relieve the load and subsequent difficulties at the treatment plant, if industry understands the problem. Municipal officials in many cases neglect to exercise control over the wastes accepted in the sewer system. Such control can be accomplished by effective ordinances and contacts with industrial officials.

The most important cog in the wheel, however, is the plant operator. His interest must go beyond the plant. He should be fully acquainted with all major wastes discharged to the sewers, should establish contacts with industries to acquaint management with the problems the wastes may create, and should lead in the efforts to control the industrial waste problem in his community.

The problem is most pronounced in small and medium-sized communities, although it is a factor for consideration in all cities. Large cities may have complex industrial waste problems, but are in a position to employ trained personnel that the smaller community can seldom afford. In a small community, the wastes from one large industry may completely dominate the treatment problem.

18.1 GENERAL EFFECTS OF INDUSTRIAL WASTES

Industrial wastes usually affect sewage collection systems and treatment plants by contributing loads in excess of the system's or plant's capacity. Some of the difficulties result from too much cooling or wash water for the hydraulic capacity, too much grease or oil on clarifier surfaces or in digesters, too many solids for grit and sludge-removal equipment, too great an organic load for secondary units, and so forth. In some cases, poisonous or toxic wastes discharged to sewer systems completely upset the biological processes at the treatment plant. Industrial operations which are seasonal place an overload on the plant during the season and an underload for the rest of the year.

The plant operator should recognize the effects of industrial wastes on the facilities for which he is responsible. Following are some of the major effects on the various units of the system and plant.

18.11 Sewer System

1. Deterioration of the sewer pipe, joints, or manholes by acids or other corrosive substances.
2. Clogging of sewers by solids such as sand, sawdust, and leaves, in excessive amounts.
3. Overload of the sewers by large continuous or intermittent flows.
4. Potential explosions due to volatile combustible solvents.

18.12 Grit Chambers

1. Rapid filling of grit channels or overloading of mechanical grit removal equipment by excessive quantities of sand and silt.
2. Increase in the organic content of grit by heavy organic solids such as fleshings from meat packing or parts of fruits and vegetables and grain from washing operations.
3. Interference with proper grit removal by large intermittent flows which carry grit into settling tanks.

18.13 Screens and Comminutors

1. Overload of screens or comminutors by large quantities of large-size particles.
2. Excessive wear on comminutor cutting surfaces by hard materials such as wood, sand, stones, and pieces of metal or metal filings.

18.14 Settling Tanks

1. Decreased settling efficiencies, caused by wide variations in flow, from the dumping of vats and tanks by certain industries.
2. Decrease in solids removal efficiencies caused by the intermittent discharge of sludges from industrial operations. (Some sludges such as lime may tend to aid settling by the formation of flocs.)
3. Scum problems from excessive quantities of oils or grease.
4. Impaired effluent quality caused by finely divided suspended solids which will not settle.
5. An undue load on sludge collection and handling facilities by large quantities of settled solids.

18.15 Sludge Digesters

1. Inorganic solids such as sand, silt, and certain industrial sludges tend to pack in digesters causing loss of capacity, plugging of sludge lines, and making frequent cleaning necessary.
2. Overload caused by excessive organic solids.
3. Increased scum layers due to oils and grease which digest slowly.
4. Acid conditions from industrial wastes which are high in sugars and starches.
5. Inhibited digestion caused by compounds such as copper, chromium, and arsenic removed with the raw sludge.

18.16 Trickling Filters

1. Clogging of filter distributor arms and pooling of filter media from finely divided suspended matter passing the settling tanks.
2. Overload from high concentrations of dissolved solids destroying biological growth and causing pooling.
3. Acid condition in the filter with subsequent loss of efficiency caused by wastes high in carbohydrates such as milk and starch wastes.
4. Destroyed filter growths caused by toxic wastes such as those containing copper, arsenic, chromium, and phenol.

18.17 Activated Sludge

1. Septic, light, and bulky activated sludge sometimes caused by wide variations from industrial waste discharges.
2. Bulking due to filamentous organisms sometimes caused by wastes high in carbohydrates.
3. Bulking or inhibited activated sludge caused by toxic wastes.

4. Loss of sludge over final clarifier weirs from wide variations in flow.

5. Foam or froth on aeration tanks from detergents and other substances contained in certain wastes from industry.

18.18 Disinfection

Organic and some inorganic substances in industrial wastes react with chlorine used for disinfection, increasing the cost of achieving satisfactory results.

18.2 INDUSTRIAL SURVEY

The first attack on the industrial waste problem should be made at its source, the industry. This requires a thorough investigation of all of the industries of the community. If the treatment plant is in the design stage, this investigation is normally the responsibility of the design engineer. However, after the plant is in operation, the operator, with the assistance of his superiors and the state agencies, must take the initiative.

All industries should be contacted and an inventory made of the quantity and characteristics of all wastes produced. If there is any doubt concerning the accuracy of this information, it may be necessary for the operator, with the help of the industry, to actually measure the quantity of waste, variations in flow, and collect and analyze samples.

Certain wastes may be accepted into the sewer system without alteration, others may require changes in composition or flow, still others must be rejected since they cannot be altered sufficiently to allow their acceptance. While it is not possible to establish exact rules regarding the acceptability of an industrial waste, there are certain considerations which will serve as guides to decisions in this regard Some of these are:

1. What will be the effect on the sewer system? Acids, for example, may damage the sewer pipe or solids may clog the system.

2. Is the nature of the waste such that it will respond to the treatment processes in use at the plant? Certain components of wastes may destroy the biological life on which treatment processes largely depend.

3. Is the concentration of the waste such that it will not interfere with the effectiveness of the processes? Wastes very high in organic matter may place excessive loads on secondary or digestion processes.

4. Do the plant units have sufficient capacity to handle the volumetric or organic load? If not, additions or expansions of the plant may be necessary.

5. How will the waste affect the plant effluent?

18.3 MODIFICATION AND CONTROL OF INDUSTRIAL WASTES FOR TREATMENT WITH SEWAGE

The following factors and waste characteristics should be considered to determine under what conditions an industrial waste should be accepted or rejected for treatment in a sewage treatment plant.

18.31 Clean Water

It is always desirable to separate clean water from other wastes at the industrial plant and to discharge this water to a storm drain or directly to a receiving waterway. Many sewage

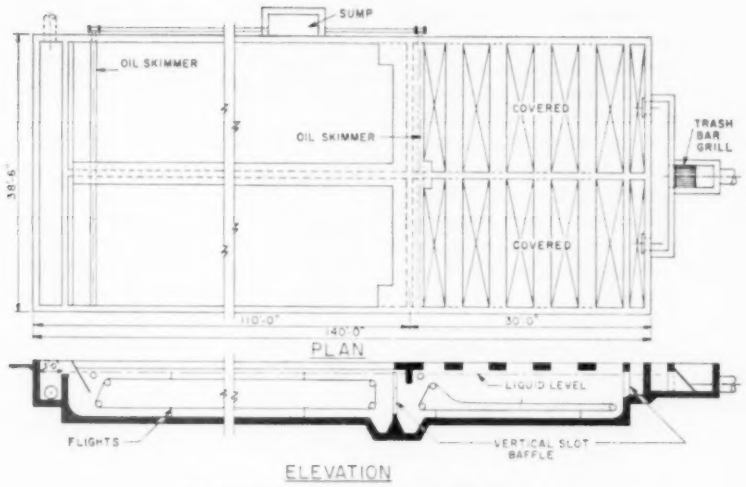


FIGURE 18-1.—Details of oil separator.

treatment plants are operating under an excessive hydraulic load and in these cases any possible reduction in flow is desirable. It is possible to obtain substantial reductions by clean water segregation. The water that usually comes under this classification is that used for cooling, refrigeration, and condensing.

18.32 Oil

Oil is a common and troublesome constituent of industrial wastes. It is not possible to prevent all oil from entering a sewer system, but it must be kept at a minimum. Oil comes from a variety of sources. Effective control requires that it be regulated through the sewer ordinance.

FIGURE 18-2.—Clarification equipment for treating oily wastes.

In the large industries where oil may be a substantial component of the waste, oil separators (Figures 18-1 and 18-2) should be installed for its removal. Effluents from such separators should not contain more than 20 mg/l of oil. Industries which may be required to provide separators include railroad roundhouses, small refineries or re-refineries, machine shops, and metal working plants. As a rule, large oil refineries should not discharge wastes to municipal sewer systems. Industries where separators are required should be referred to the design information given in American Petroleum Institute bulletins.

Railroad tank cars, tank trucks, and other facilities used for loading, unloading, storage, or transportation of oil and having a drain connection to the sewer system should be equipped for the collection of the drip and excess oil contained in hose and pipe lines. Provision should be made for catching accidental spills and these facilities should be large enough to hold the maximum quantity of oil possible from any spill.

Garages and service stations should be required to collect waste oil in containers. In some cases, it may be necessary to require that small oil sumps be built to keep the oil from entering the system. Machine shops should collect waste cutting-oil emulsions for reuse or separate disposal and should operate an oil sump for general cleanup water.

18.33 Explosive and Flammable Substances

Explosive or flammable substances should never be allowed in the sewer system. Disasters such as have occurred in numerous cities should be sufficient reason for strict ordinances to prevent the discharge of them to the system. These ordinances must be enforced. Certain dry-cleaning fluids, chemical solvents, and gasoline are examples of this type of substance.

18.34 Acids and Alkalis

Acids may damage sewer pipe in the vicinity of the discharge, especially if the pipe is concrete. It may be necessary to alter the method of discharge or require that the acid be neutralized if damage is found.

Acids and alkalis are often dumped to the sewer in batches. These discharges may or may not significantly affect the pH of the sewage as it enters the treatment plant. The operator by knowing the schedule of dumping and by a series of pH tests following the dumps can determine whether damage will result. Sewage influent pH values should range between 6.5 and 8.5. If the pH is outside this range, it may be corrected by either spreading the time of discharge over a longer period or by neutralizing the acid or alkali. In some cases, it will be necessary to provide storage tanks from which the acid or alkali solutions may be dripped into the factory drain at a low rate. Tests at the plant will determine the effectiveness of this method.

Neutralization may be accomplished by the use of acids or alkalis or by mixing wastes of different characteristics. For instance, one industry may have an acid waste while another may want to dispose of an alkaline sludge. Under certain conditions it is possible to bring these two wastes together.

If these methods fail to produce a waste acceptable in the system, other means of disposal must be found.

18.35 Toxic Substances

Some components of industrial wastes in certain concentrations are toxic to the biological life necessary for most sewage treatment processes. While the operator cannot be an expert in detecting these toxic compounds, he can by contact with the industry determine the possible presence of such substances in the wastes discharged to the sewers. Some of the more common substances to look for are:

1. The metal ions such as copper, chromium, nickel, and zinc, and the cyanides of metals. All or any of these may be found in the wastes from metal plating rooms in various concentrations.

2. Insecticides, fungicides, and sprays.

3. Chemicals from chemical manufacturing.

4. Phenols and plastic resins.

5. Certain glues.

As in the case of acids and alkalis, the industry may customarily dump concentrated solutions of these materials in batches. As a rule, it is desirable to find some means of disposal of these concentrated solutions other than by dumping to the sewer. It may be necessary to accept weaker solutions such as washings in which case it is imperative that a constant check be devised to assure that the quantity of the toxic agent will not be sufficient to inhibit the treatment process. The industry should be required to either pretreat, dilute, or extend the period of discharge as needed. Unless the operator is well acquainted with the characteristics of these substances, he should obtain advice regarding those discharged to the system for which he is responsible.

TABLE 18-1.—Typical Wastes from Industrial Operations

Industry	Production Unit	Flow (gal/production unit)	BOD (mg/l)	SS (mg/l)	Population Equivalent	
					BOD (per production unit)	SS (per production unit)
Meat Packing						
Stockyard	One acre	25,000	65	175	80	180
Slaughterhouse, hog	One hog[a]	143	1,048	717	8	4
Slaughterhouse, cattle		157	998	820	8	5
Slaughterhouse, mixed		160	2,200	930	18	16
Packing plant, mixed		550	900	650	24	14
Poultry	1,000 lb	2,200	—	1,460	300	160
Milk Products						
General dairy	1,000 lb raw milk	340	570	540	10	8
Receiving station		175	500	280	4	2
Bottling plant		250	500	280	6	3
Creamery		110	1,250	660	6	3
Condensery		150	1,300	750	7	4
Condensery vacuum pan		1,500	25	—	2	—
Dry milk powder		300	480	500	6	6
Cheese factory		200	1,600	750	16	9
Canning						
Fruits						
Apricots	100 cases No. 2 cans	8,000	1,020	260	416	800
Cherries, sweet	100 cases No. 2½ cans	16,500	470	20	380	10
Cherries, sour, pitted	100 cases No. 2½ cans	16,500	750	—	600	—
Grapefruit	100 cases No. 2 cans	5,600	1,850	270	500	50
Grapefruit juice	100 cases No. 2 cans	500	310	170	8	3
Pears	100 cases No. 2½ cans	6,500	1,340	400	440	100
Peaches		6,500	1,340	400	440	100
Prunes & Plums		8,000	1,020	260	410	80
Apples	100 cases No. 10 cans	11,600	1,110	—	900	—
Grapes	Ton of raw grapes	100	720	—	3.6	—
Tomatoes, whole	100 cases No. 2 cans	800	4,000	2,000	150	60
Tomatoes, products		7,000	1,000	560	350	150
Tomatoes, puree		800	2,900	950	110	30
Vegetables						
Asparagus	100 cases No. 2 cans	7,000	100	30	35	9
Beans, green		3,500	200	60	35	9
Beans, lima		25,000	190	420	240	440
Beans, wax		2,600	240	60	20	6
Beans, pork and		3,500	920	225	160	33
Beets		3,700	2,600	1,530	480	240
Carrots		3,700	1,630	1,830	300	260
Corn, cream		2,500	620	300	75	30
Corn, kernel		2,500	2,000	1,250	250	130
Peas		2,500	1,700	400	210	40
Sauerkraut		300	6,300	630	100	10
Spinach		16,000	620	580	480	370
Pumpkin	100 cases No. 2½ cans	2,500	6,400	1,850	800	190

TABLE 18-1.—*Continued.*

Industry	Production Unit	Flow (gal/production unit)	BOD (mg/l)	SS (mg/l)	Population Equivalent	
					BOD (per production unit)	SS (per production unit)
Dried and dehydrated vegetables						
Potatoes, abrasive peeled	Ton of raw potatoes	500	1,000	—	120	—
Potatoes, spray washed	Ton of raw potatoes	2,500	1,000	—	120	—
Beet Sugar						
Flume water	Ton of raw beets	2,200	200	800	22	74
Process water		660	1,230	1,100	40	30
Lime cake drainage		75	1,420	450	5	14
Steffens waste		120	10,000	7,700	60	35
Brewery						
Grain dewatered	Bbl. of beer	470	1,200	650	19	9
Grain sold wet	Bbl. of beer	470	800	450	12	6
Distillery						
Combined	Bu of grain	600	1,230	350	35	23
Molasses	Gal 100 proof	8	33,000	3,270	12	1
Paper Mill						
Unbleached	Ton of paper	39,000	19	450	26	520
Bleached		47,000	24	156	40	2,200
Paperboard		14,000	121	560	97	447
Strawboard		26,000	965	1,790	1,230	1,920
Deinking		83,000	300	—	1,250	—
Pulp Mill						
Groundwood	Ton of pulp	5,000	645	—	16	—
Soda		85,000	110	1,720	460	6,100
Kraft		64,000	123	—	390	—
Sulfite		60,000	443	—	1,330	—
Tanning						
Vegetable	100 lb of hides	800	1,200	2,400	48	80
Chrome		3,470	460	3,760	80	545
Laundry	100 lb of clothes	1,485	320	—	24	8
Oil refining	Bbl crude	770	20	50	0.6	1.2

Note: The above data in this table have been taken largely from Supplement "D," Ohio River Pollution Survey Report, U. S. Public Health Service (1942).
* 2.5 hog units = 1 head of cattle; 1 hog unit = 1 lamb = 1 calf; all in terms of waste.

18.36 Organic Wastes

The largest group of industrial wastes to be considered are those containing organic material. These wastes are of such a character that they will normally respond to treatment by biological processes such as those employed for the treatment of domestic sewage.

The strength of an organic waste is best measured by its BOD. The BOD of many organic industrial wastes on a unit volume basis exceeds that of domestic sewage. It is desirable that the operator have a means by which he can compare the BOD load of an industrial waste with that of sewage. A determination of the population equivalent (PE) provides this means. One PE is equal to 0.17 lb/day of BOD per day. Pounds of BOD are determined from the flow rate and concentration of BOD of the waste.

Table 18-1 contains typical analyses of most of the major industrial wastes. These data should be used only for the purpose of estimation and do not take the place of results obtained from actual tests made on the specific waste.

The suspended solids content of the industrial wastes discharged to a treatment plant and especially the volatile portions of these solids are of interest to the plant operator. In the primary portion of the plant, these solids add to the load on the digester. To compare the industrial waste with domestic sewage on the basis of the suspended and volatile solids, these may also be expressed in terms of population equivalents. One PE on the basis of sus-

pended solids equals 0.21 lb/day and of volatile solids, 0.14 lb/day.

The decision as to the acceptability of an organic industrial waste for treatment in a municipal sewage treatment plant is largely a matter of economies although other factors may influence the decision. All factors being equal, it is preferred to accept the waste for treatment. In some cases, however, wastes can be more economically and effectively disposed of or treated by other means. In other cases, it may be desirable to require pretreatment before the wastes are discharged to the sewer system. In any case, the minimum requirement should be that the industry initiate an effective waste prevention program to reduce the organic load to be handled. Waste prevention is usually applied to the more concentrated portions of the industrial waste and thus results in a substantial reduction in organic matter at a lesser cost than is involved in treatment. Often such waste prevention measures result in a saving to the industry.

Waste disposal problems vary widely in the different industries and even from plant to plant in the same industry. Consideration, however, of each major industry in a general way will indicate items and factors which may act as guides to the operator in his dealings with the industries in his community.

18.361 Meat Packing Industry:—Wastes from slaughterhouses, meat packing plants, and poultry processing facilities contain blood, paunch manure, fleshings, grease, and feathers, in quantities depending on the animal. In most cases there is no reason for this material to be discharged to the sewer; the exception would be that portion which may be contained in the wash waters. With the following minimum requirements in effective use, no difficulty will normally be experienced in handling the washings from meat and poultry packing operations:

1. Yards and holding pens should be dry-cleaned before wash down. This will remove a large portion of the straw and offal which can then be used on land as fertilizer.

2. Kill-blood should be collected separately in a blood tank along with the blood which collects on the floor. The latter should be scraped into a drain leading to the blood tank. The disposal of this blood will depend on local facilities for utilization. Usually, it is sold for rendering or drying or may be used in the manufacture of compost.

3. Paunch manure and hog-stomach contents should be collected and used for fertilizer or composting. A fine screen and storage hopper are recommended whenever such an installation is possible. This equipment will facilitate handling.

4. Fleshings, grease particles, and other solids should be collected by dry-cleaning the floors and equipment before washing, and by the use of an effective screen for the total plant wastes.

5. Grease traps should be installed on drain lines from the by-product rooms. Traps should be skimmed and cleaned at least once a day preferably in the morning when the waste is cold and the grease solidified.

6. All manure, feathers, entrails, and other solids from poultry processing should be collected and the floors and equipment dry-cleaned before wash down. Provision should be made for the continuous disposal of this material.

7. A grease trap and settling basin for the total plant flow are often desirable.

18.362 Dairy Industry:—Milk solids respond readily to secondary treatment processes. However, they have a high oxygen requirement and are often the cause of organic overloads in treatment plants. If the milk solids in the sewage received at the plant are excessive, the sewage becomes sour with the resulting low pH and unpleasant odors.

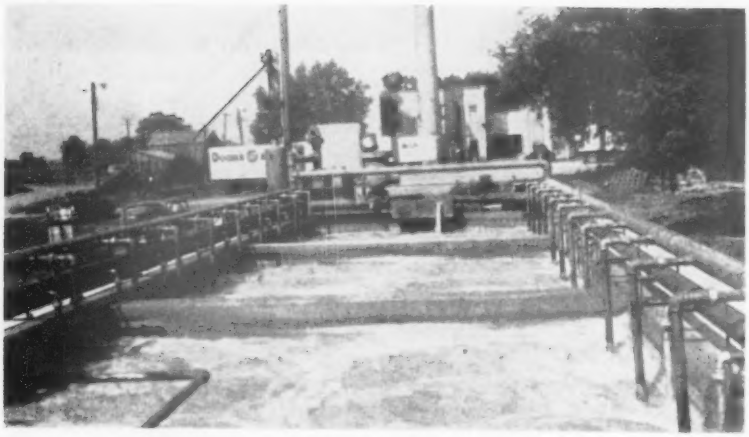


FIGURE 18-3.—Aeration treatment of milk waste.

Filters become clogged and activated sludge becomes light and bulky.

This is one industry where good housekeeping methods and waste prevention result in a profit to the industry. A task committee of the dairy industry has recommended waste-prevention measures of which the following should be the minimum required when a processor is connected to a municipal sewer:

1. Whole milk, skim milk, buttermilk, whey, condensed milk products, dried milk, or spoiled milk should never be discharged to the sewer system.

2. Mechanical can washers, both straight-line and rotary, should be equipped with drip collectors. Usually, the milk collected is returned to the farm for feeding.

3. Milk or milk products left in sanitary lines, tanks, and equipment should be drained into suitable containers for disposal along with the drip from the can washer.

4. Leaks in pumps, pipelines, and other equipment handling milk or milk products should be repaired as soon as possible.

5. Accidental spillage should be reduced to a minimum by providing appropriate alarms or automatic equipment to prevent overflow of tanks.

6. Condenser, ice machine, and other clean water should be segregated for disposal in storm drains or direct to a receiving water.

Even with these requirements in effect, the organic load contributed by the washings from a milk industry may in some cases be greater than the capacity available at the sewage treatment plant. In such a case, it may be necessary to require pretreatment prior to discharge to the system. Milk waste responds readily to aeration and a reduction in BOD up to 50 per cent is possible by aeration over a 24-hr period (Figure 18-3). This appears to be a simple and inexpensive pretreatment method where a reduction of organic load in this range is necessary. Biological filtration or the activated sludge process can be used if a greater reduction in BOD is required.

18.363 Canning Industry:—Wastes from vegetable and fruit canneries wherever possible should be disposed of by other means than by treatment in a municipal plant. These canneries usually operate only for a period of six weeks to three months each year. They contribute a large BOD and volumetric

load which necessitates an available capacity in the treatment plant which is not required for the major portion of the year. This factor creates operational problems due to overload during the canning season and underload during the rest of the year. Exceptions to this statement may be small canneries in larger communities.

The canning industry has found that irrigation and lagooning of waste are the more effective and least expensive methods of disposal. Local conditions and available land are factors which influence the use of these methods. Figure 18-4 shows a spray irrigation installation.

In those cases where it is necessary to treat cannery wastes in a municipal plant, the minimum requirement should be effective screening and segregation of clean water. The screen is necessary to remove skins, seeds, pomace, culls, discarded product, and other suspended material from washing, sorting, and other processes. This screen should be 20-mesh and may be of the vibrating, rotary, or any other effective type. It should be located on the main sewer line of the cannery in such a manner that all wastewater except cooling and clean waters will pass through it.

18.364 Wine Industry:—Wastes from dry wine manufacture consist of pomace, lees, and wash water. If the process involves the manufacture of brandy, still slops will result from distillation processes. In most cases, the washings can be accepted for treatment at the municipal plant. The major portion of the pomace, lees, and still slops must be collected and disposed of for feed production, land application, or some other method.

18.365 Brewing Industry:—Under no condition should brewer's grain be discharged to the municipal system. These grains have a market value and are usually recovered and sold for cattle feed. Because of the high concentration of organic solids in the grain liquor, the grain should be sold in a wet condition wherever possible. If the grain is dehydrated, it may be necessary to give special consideration to the disposal of the liquor since if discharged to the treatment plant it may cause an overload in the secondary units.

Spent hops should be collected for disposal on land or by incineration. The major portion of the yeast should be recovered for use in cattle feed. These operations are normal in most breweries using up-to-date methods. Wash waters may usually be accepted for treatment in the municipal plant.

18.366 Tanneries:—Tannery wastes are seldom accepted for treatment in a municipal plant except in the case of a small custom tannery. Wastes from these operations contain a high concentration of suspended solids, are high in BOD, and may be either acid or alkaline depending on the tanning process in use. These wastes are often dumped in batches of concentrated material which causes sudden loads to be placed on treatment processes.

If the tannery is so located that it becomes necessary to dispose of the liquor wastes by way of the sewer system, the following minimum pretreatment should be required:

1. Wastes from the beam house and other wastes containing hair and fleshings should be passed through a screen and the screenings removed for separate disposal. Screen openings should be about $\frac{1}{8}$ in. in diameter.

2. Lime sludge should be removed from the vats in as dry a condition as possible and disposed of as fill or on land.

3. Vegetable-tan liquors or chrome liquors should be mixed with the liquid waste from the beam house. This will produce a more neutral mixture and will cause the precipitation of considerable material which should be removed by settling in a pond or settling tank. The sludge from this operation

FIGURE 18-4.—Spray irrigation of canning waste.

should be dried and used for fill or applied to land.

18.367 Laundries:—In some cases, laundry wastes may cause difficulties in the operation of sewage treatment plants although in the majority of cases they have no great significance. The wastes are alkaline and contain grease, dirt, soap, and detergents. Much of the suspended matter is light and collects on the surface of settling tanks thereby increasing scum problems. The BOD may be several times that of domestic sewage. In plants employing aeration, detergents often cause foaming. Soaps and grease from laundry wastes may disturb digestion processes. If these situations become acute, it may be necessary to require the pretreatment of the wastes.

18.37 Industries with Unacceptable Wastes

Wastes from the following industries are not normally acceptable in a municipal sewage treatment plant: (*a*) pulp and paper, (*b*) beet sugar or cane sugar, (*c*) rayon, (*d*) oil refining, (*e*) coke and gas manufacturing, (*f*) metal plating, (*g*) synthetic and reclaimed rubber, (*h*) sawmills, (*i*) veneering, (*j*) mines, (*k*) gravel operations, and (*l*) wool scouring.

Other chapters of this manual describe the operations of the various units of the sewage treatment plant. Industrial wastes may add to the loads to be handled by these units or cause some variation in the operations. If the loads are excessive, this condition will be apparent to the operator. In such cases, either the load must be reduced or the plant enlarged. Some adjustments may make it possible to handle the load until changes can be made, but these adjustments are so dependent on the specific conditions that no general rules or recommendations can be applied. Improvisation by the operator is usually necessary.

NEWS AND NOTES

People and Events in the Wastewater Field

N. S. Bubbis has been appointed Director of the Waste and Waterworks Division of the Metropolitan Corporation of Greater Winnipeg, Manitoba. This is a newly-formed corporation which is responsible for the functions of the former Greater Winnipeg Water and Sanitary Districts.

Clyde L. Palmer has assumed the duties of City Engineer of Detroit, Mich. He has been Assistant City Engineer since 1954.

Kenneth W. Brown, Partner in the firm of **Brown and Caldwell** in San Francisco, died recently.

Several organization changes have occurred at *Wastes Engineering*. **Morris M. Cohn** has assumed the position of Editorial Director; **Kenneth H. Walker** has been named Editor; and **Richard T. Dewling** has become Assistant Editor. **Frank Reid**, former Associate Editor, has been transferred to Chicago where he will serve as Editor of *Street Engineering* and Associate Editor of *Roads and Streets*.

Philip Morgan, Professor of Sanitary Engineering at the State University of Iowa, died recently.

George E. Barnes, Professor of Hydraulic and Sanitary Engineering at Case Institute of Technology, is on leave of absence to serve on the faculty of Central University of Venezuela in Caracas, where he will be Visiting Professor of Sanitary Engineering for the spring semester.

L. S. Morgan, Chief of the Pennsylvania Health Department's Mine Drainage Section, has resigned after 36 years of service to become Director of Environmental Health for the Bucks County Health Department.

Frank A. Butrico has been appointed to the position of Assistant Chief Engineer for the Public Health Service in the immediate office of the Surgeon General and working directly with the Chief Engineer.

The outstanding stock of **Infilco Incorporated** has been acquired by General American Transportation Corporation.

Henry C. Marks, formerly Director of Research for **Wallace and Tiernan's** Chemical and Pharmaceutical Divisions, has been made Director of all divisions.

Russell Culp has resigned from the Kansas State Board of Health and has joined **Cornell, Howland, Hayes and Merryfield** in Corvallis, Ore.

D. W. Maloney has resigned as Superintendent of Utilities at Platte City, Mo., to accept the position of Supervisor of Sewage Treatment Plant Operations for Kansas City, Mo.

Edmund C. Garthe, who recently retired from the Public Health Service, has been named Assistant Director of the Kentucky State Department of Health's Bureau of Environmental Health.

Clarence E. Harness, Deputy Manager of Public Works for Denver, Colo., died recently.

William G. Riddle has formed the firm of William G. Riddle and Associates, Country Club Plaza at 47th and Belleview, Kansas City, Mo.

W. W. Hodge, Senior Fellow at Mellon Institute of Industrial Research, Pittsburgh, Pa., died recently.

A. E. Griffin has retired from **Wallace and Tiernan** and is now a water treatment consultant at 24 Sunset Road, Pompton Plains, N. J.

Francis B. Elder, Engineering Associate of the American Public Health Association, recently was inaugurated President of the New Jersey Public Health Association.

Morris B. Cunningham, Superintendent of the Oklahoma City water department, recently became the sixth member of the Oklahoma State University Engineering Hall of Fame.

A. P. Black, Research Professor of Chemistry at the University of Florida, has been elected to a third 5-yr term as a member of the College of Electors of the Hall of Fame for Great Americans at New York University.

Lock Joint Pipe Co., East Orange, N. J., has acquired Electro Chemical Engineering and Manufacturing Co. of Emmaus, Pa., and its associated companies.

MAILING LIST CONVERSION

An Editorial

Was the name and address on the wrapper that brought this Journal to you correct in every detail? If not please take the time to indicate necessary changes and send it to the Federation office immediately. Please note that the order of your name on this address is surname, followed by first name or initials. If it is in that order now, no change in the name is necessary. However, any changes in the street address or post office including zone numbers should be made.

Starting with the June Journal, a new system combining membership and mailing information on a punch card will be used. This card will include (*a*) Journal mailing address, (*b*) directory entry, (*c*) occupational classification, (*d*) Member Association designation, (*e*) type of Federation membership, (*f*) year of earliest membership, (*g*) record of dues payment, and (*h*) detailed geographic data.

To prevent confusion of certain first and last names the new system will include the use of all names in normal order rather than surnames first. Because of the limited number of characters on a line, titles will be omitted.

The street and post office address should be the simplest reliable address, except in rare instances. For example, "312 City Hall, Milwaukee Heights 6, Wisconsin," is far better from the standpoint of assured postal delivery than "Assistant City Engineer, Dept. of Public Works, Milwaukee Heights, Wisconsin."

The Directory block of your membership card will be used for the biennial membership directory, the last of which was printed as Part 2 of the March 1960 Journal (the red one). A supplementary directory was published in the March 1961 Journal.

All Journal recipients are separated according to their effort classification in eleven groups. The numbers following your Member Association designation on the name line of your present stencil imprint designate the category in which you are now "counted." These classifications are:

1. Consulting engineers
2. Municipal engineers
3. Municipal officials
4. Public health engineers
5. Education and research personnel
6. Industrial wastes engineers and chemists
7. Libraries
8. Military personnel
9. Manufacturers and representatives
10. Students
11. Works superintendents, operators, and chemists

If you are not in one of these classes, you are described as "miscellaneous or unknown" and designated by the number 12. If your classification does not agree with your present work, please send correct information to the Federation office promptly.

If you will supply the Federation office as well as your Member Association Secretary with all this information promptly, we will do all possible to maintain records that will assure prompt delivery of the Journal to you monthly and the proper entry of your Directory information. Since this information can come only from you, we urgently request that you make this check immediately and send us any changes that should be made. Also, please inform your Member Association Secretary and the Federation office as far in advance as possible of any address change in order that we may serve you better.

R. E. F.

VAREC GAS BURNER

"A CURTAIN OF FLAME" INSURES POSITIVE IGNITION OF WASTE GAS

Varec engineers designed a double orifice in the pilot flame ring (A). The ring encircles the waste gas nozzle (B)... forms an actual "curtain of flame" that all waste gas must pass through... and which positively ignites the gas.

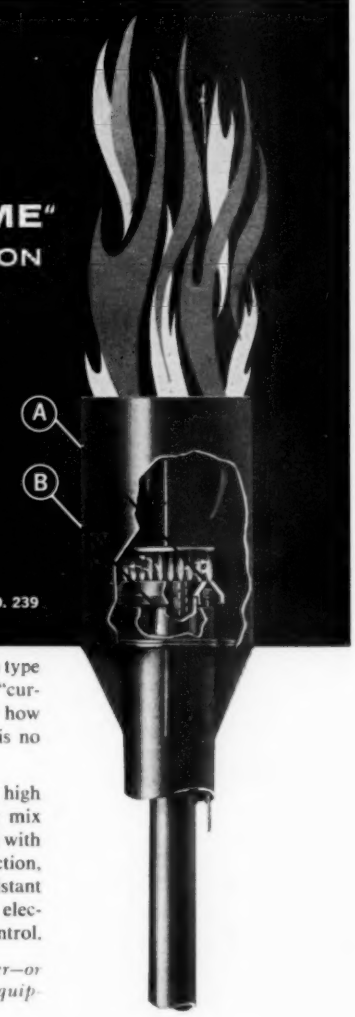


FIG. NO. 239

Varec eliminates ignition problems with its new flare type Fig. No. 239 Waste Gas Burner. The burner's unique "curtain of flame" provides dependable ignition no matter how variable the flow of gas through the burner. There is no loss of pilot flame due to down draft.

Other outstanding features of the new unit include its high burning capacity... an adjustable shutter on the air mix chamber that regulates draft... a high pedestal, packed with insulation to prevent freezing... and rugged construction, with all parts made of steel, stainless steel or heat-resistant cast iron. For critical service, sensing and ignition electrodes are available for remote or automatic pilot control.

For full information on the Varec Waste Gas Burner—or Varec's complete line of advanced design gas control equipment, write for Catalog S-4, Dept. JWP-1222-5.

"Varec" TRADE ® MARK

THE VAPOR RECOVERY SYSTEMS COMPANY
2820 North Alameda Street • Compton, California
Branches and Representatives in Principal Cities

WATER POLLUTION CONTROL PRODUCT GUIDE

This list of products and services is offered as an information aid. The list was derived by solicitation from those firms listed. The JOURNAL will make every effort to keep this list current with the help of Associate Members and advertisers. All Associate Members and all advertisers for the past year are included. Many of the services and products are advertised in this issue. For an alphabetical listing see Index to Advertisers in back of JOURNAL.

Aerators (*also see* Diffusers, Air)
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Infilco Inc.
Link-Belt Co.
Pacific Flush Tank Co.
Penberthy Mfg. Co., Div. of Buffalo-Eclipse Corp.
Permutit Co., Div. of Pfaudler Permutit Inc.
Smith & Loveless
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.
Yeomans Brothers Co.
Zimmer & Francescon

Agitators
Link-Belt Co.

Air Cleaning Equipment
Westinghouse Electric Corp.

Air Compressors (*also see* Blowers, Compressors, and Fans)
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Worthington Corp.
Yeomans Brothers Co.

Air Diffusers (*see* Diffusers, Air)

Asbestos Cement Pipe Products
Filtration Equipment Corp.
Industrial Materials Co.
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Ash Handling Equipment
Link-Belt Co.

Bearings
Link-Belt Co.

Bins, Storage (*see* Tanks)

Biologists (*see* Professional Services, elsewhere in this issue)

Blowers (*also see* Air Compressors, Compressors, and Fans)
Chicago Pump Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Sutorbilt Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Boilers
Combustion Engineering, Inc.

Building Maintenance Equipment and Supplies
Homestead Valve Mfg. Co.

Cast Iron Pipe Products
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Industrial Materials Co.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Cement (*see* Concrete)

Centrifuging Equipment
Bird Machine Co.
Permutit Co., Div. of Pfaudler Permutit Inc.

Chains
Chain Belt Co.
Link-Belt Co.
Webster Mfg., Inc.

Chemical Feed Equipment
Builders-Providence Div., B-I-F Industries
Eimco Corp.
Fischer & Porter Co.
Graver Water Conditioning Co.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Link-Belt Co.
Omega Div., B-I-F Industries
Permutit Co., Div. of Pfaudler Permutit Inc.
Proportioneers Div., B-I-F Industries
Wallace & Tiernan Inc.

Chemicals
Dow Chemical Co.
Fisher Scientific Co.
General Chemical Div., Allied Chemical Corp.
Glenn Chemical Co.
Hach Co.
Tennessee Corp.

Chemists (*see* Professional Services, elsewhere in this issue)

Chlorination Equipment
Builders-Providence Div., B-I-F Industries
Everson Mfg. Corp.
Fischer & Porter Co.
Graver Water Conditioning Co.
Wallace & Tiernan Inc.
Zimmer & Francescon

Clarifier Equipment (*also see* Sedimentation Equipment)
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Link-Belt Co.
Permutit Co., Div. of Pfaudler Permutit Co.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Clay Pipe Products
Industrial Materials Co.
National Clay Pipe Mfrs., Inc.
National Sewer Pipe Ltd. (Canada)
Robinson Clay Product Co.

Coatings and Linings (Pipe and Tank)
Amercoat Corp.
Centriline Corp.
Corrosion Control Co., Inc.
Inertol Co., Inc.
Koppers Co., Inc.
National Water Main Cleaning Co.
Perry-Austen Mfg. Co.
Stebbins Engr. & Mfg. Co.

Comminutors (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Infilco Inc.
Jeffrey Mfg. Co.
Smith & Loveless
Walker Process Equipment Inc.
Worthington Corp.

Compressors
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Worthington Corp.
Yeomans Brothers Co.

Computers
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.

Concentrators (*see* Sludge Concentrators)

Concrete
Portland Cement Assn.

Concrete Pipe Products
American Concrete Pressure Pipe Assn.
American-Marietta Co.
Gray Concrete Pipe Co., Inc.
Industrial Materials Co.
Lock Joint Pipe Co.
National Sewer Pipe Ltd. (Canada)
Portland Cement Assn.
Price Brothers Co.

Construction Equipment
Chain Belt Co.
Eimco Corp.
Worthington Corp.

Protective Coatings—A 13-page illustrated booklet describes a complete line of coal tar coatings. Bulletin CAC-11-958, Plastic and Coal Chemicals Division, Allied Chemical Corporation, 40 Rector St., New York 6, N. Y.

Subsurface Exploration — Seismic methods are said to be economically feasible by use of a lightweight, self-powered, portable seismic timer. The Model 117 timer is said to permit explorations to depths of 50 ft or more. —Dyna Metric, Inc., 2955 E. Colorado Blvd., Pasadena, Calif.

Nitrogen Analyzer—An automatic nitrogen analyzer has been built utilizing the micro-Dumas method. It is claimed to be suitable for making numerous determinations now done by the Kjeldahl method. The price is $2,495.—Bulletin B-258, Coleman Instruments, Inc., 42 Madison St., Maywood, Ill.

Nitrogen analyzer.

Package Plant—A 12-page brochure describes the aerobic digestion plants. Two types of units are available: one for flows up to 15,000 gpd, and the other for flows between 15,000 and 200,000 gpd.—Bulletin SM 1010, Eimco Corporation, P. O. Box 300, Salt Lake City 10, Utah.

Table Tops—Asbestos-cement sheet material for table tops is described in a 12-page booklet on Colorlith, a product of the Johns-Manville Corporation, 22 East 40th St., New York 16. Ask for IN-296A.

Bar Screen Cleaning—Various control systems used to clean bar screens automatically are described in Data Sheet 9.7-1. The liquid-level differential is the basis for control. Minneapolis-Honeywell Regulator Company, Industrial Division, Philadelphia 44, Pa.

Fiber Pipe—A new kind of pitch-impregnated fiber pipe, available in diameters from 4 to 36 in., has been developed by the Sonoco Products Co., Hartsville, S. C. It features spiral-laminated construction.

Package Plant—Complete information on the Accleo-Biox treatment plant is contained in Bulletin 6520, Infilco Inc., Tucson, Ariz. A Vortair aerator entrains air, and mixes, recirculates sludge, and clarifies with a single tank. The plants come in various sizes, the largest being capable of treating the wastes from a population of 3,000.

Combustible Gas Indicator—Johnson-Williams, Inc., Palo Alto, Calif., manufactures a portable combustible gas indicator which sells for about $100. The unit is termed the J-W SNIFFER, Model G.

Clutches—"Modern Clutching for Water and Sewage Treatment Plants" is the title of Bulletin No. 305 of the Centric Clutch Co., P. O. Box 175, Woodbridge, N. J. As far as is known, this is the first bulletin of this nature produced for the wastewater field.

Controls (*also see* Instruments, Recording and Control)
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Chicago Pump Co.
Fischer & Porter Co.
Foxboro Co.
General Electric Co.
Homestead Valve & Meter Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Ohmart Corp.
Permutit Co., Div. of Pfaudler Permutit Co. Inc.
Rockwell Mfg. Co.
Wallace & Tiernan Inc.
Westinghouse Electric Corp.
Worthington Corp.

Conveyors
American Well Works
Chain Belt Co.
Chicago Pump Co.
Jeffrey Mfg. Co.
Link-Belt Co.
Stuart Corp.
Webster Mfg., Inc.

Corrosion Protection
Amercoat Corp.
Chicago Pump Co.
Corrosion Control Co., Inc.
Inertol Co., Inc.
Johns-Manville Sales Corp.
Koppers Co., Inc.
Perry-Austen Mfg. Co.
A. O. Smith Corp.
Stebbins Engr. & Mfg. Co.
Wallace & Tiernan Inc.

Couplings
Link-Belt Co.

Diffusers, Air (*also see* Aerators)
Alpha Ltd. (Switzerland)
American Well Works
Carborundum Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Penberthy Mfg. Co., Div. of Buffalo-Eclipse Corp.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.
Zimmer & Francescon

Diffusers, Gas (*also see* Aerators)
American Well Works
Carborundum Co.
Chicago Pump Co.
Eimco Corp.
Infilco Inc.
Walker Process Equipment Inc.
Yeomans Brothers Co.

Digestion Tank Equipment
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Gorman-Rupp Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
A. O. Smith Corp.
Smith & Loveless
Vapor Recovery Systems Co.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Distributors, Rotary
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Smith & Loveless
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Dryers
Alpha Ltd. (Switzerland)
Combustion Engineering, Inc.
Eimco Corp.
Hardinge Co., Inc.
Komline-Sanderson Engr. Corp.
Link-Belt Co.
Nichols Engr. & Research Corp.
Stuart Corp.

Ejectors
Komline-Sanderson Engr. Corp.
Smith & Loveless
Tex-Vit Mfg. Co.
Yeomans Brothers Co.

Engineers (*see* Professional Services, elsewhere in this issue)

Engines (Sludge Gas and Petroleum Fuels)
Fairbanks, Morse & Co.
Waukesha Motor Co.
Worthington Corp.

Fans (*also see* Air Compressors, Blowers, and Compressors)
Chicago Pump Co.
Lakeside Engineering Corp.
Westinghouse Electric Corp.

Filter Equipment, Trickling
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Dorr-Oliver Inc.
Dow Chemical Co.
Eimco Corp.
Filtration Equipment Corp.
Industrial Materials Co.
Infilco Inc.
Keasbey & Mattison Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Nichols Engr. & Research Corp.
Pacific Flush Tank Co.
Smith & Loveless
Trickling Filter Floor Inst.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Filter Materials
Carborundum Co.
Filtration Equipment Corp.
Glenn Chemical Co.
Graver Water Conditioning Co.
Industrial Materials Co.
Johns-Manville Sales Corp.

Filters, Diatomaceous Earth
Graver Water Conditioning Co.
Yeomans Brothers Co.

Filters, Vacuum (*also see* Vacuum Filters)
Bird Machine Co.
Dorr-Oliver Inc.
Eimco Corp.
Proportioneers Div., B-I-F Industries

Flocculating Equipment
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Permutit Co., Div. of Pfaudler Permutit Inc.
Stuart Corp.
Walker Process Equipment Inc.
Webster Mfg., Inc.
Zimmer & Francescon

Flotation Equipment
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Komline-Sanderson Engr. Corp.
Yeomans Brothers Co.

Flow Measurement
Burgess-Manning Co., Penn Instruments Div.
Filtration Equipment Corp.

Gas Control Equipment
Alpha Ltd. (Switzerland)
Burgess-Manning Co., Penn Instruments Div.
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Foxboro Co.
Homestead Valve Mfg. Co.
Pacific Flush Tank Co.
Rockwell Mfg. Co.
Vapor Recovery Systems Co.
Walker Process Equipment Inc.
Zimmer & Francescon

Gas Diffusers (*see* Diffusers, Gas)

Gas Holders, Boilers, and Appurtenances
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Johns-Manville Sales Corp.
Walker Process Equipment Inc.

Gaskets
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Gates
Armco Drainage & Metal Products, Inc.
Filtration Equipment Corp.
Industrial Materials Co.
Snow Gates & Valves, Inc.
Webster Mfg., Inc.

Generators
Fairbanks, Morse & Co.
General Electric Co.
Westinghouse Electric Corp.
Worthington Corp.

Grinders (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Yeomans Brothers Co.

Grit Collection and Conditioning Equipment
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Stuart Corp.
Walker Process Equipment Inc.
Webster Mfg., Inc.
Zimmer & Francescon

STANDARD METHODS
11th EDITION

- **NEW TITLE** — Standard Methods for the Examination of Water and Wastewater.
- **JOINTLY PRODUCED** — American Public Health Association (Publisher), American Water Works Association, and Water Pollution Control Federation.
- **DETAILED COVERAGE** — Laboratory manual and reference of more than 600 pages covering simple and detailed methods for physical, chemical, bacteriological, and biological analyses of water and wastewater.
- **NEW COVERAGE** — More than 100 pages added; new sections on radiology, bio-assays for toxicity of industrial wastes, and iron and sulfur bacteria.
- **ORDER NOW** — Special price of $8 to members of any of the three sponsoring organizations if prepaid; without remittance, $10.

- **USE THIS COUPON**

WATER POLLUTION CONTROL FEDERATION
4435 Wisconsin Avenue, Washington 16, D. C.

Publication: STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 11th Edition.

Enclosed is remittance for $.....

.....
Print Name

.....
Address

....
City Zone State

.....
Federation Member Association

If an invoice is necessary, postage will be added.
Checks may be made payable to WPCF.

Grounds Maintenance Equipment and Supplies
Homestead Valve Mfg. Co.

Heating Equipment for Digesters and Buildings
Alpha Ltd. (Switzerland)
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
General Electric Co.
Infilco Inc.
Link-Belt Co.
Pacific Flush Tank Co.
Walker Process Equipment Inc.

Incinerators
Combustion Engineering, Inc.
Nichols Engr. & Research Corp.
Walker Process Equipment Inc.
Zimmermann Process Div. of Sterling Drug Inc.

Insect Control
Glenn Chemical Co.

Inspection, Sewers
Centriline Corp.
National Water Main Cleaning Co.

Instruments, Recording and Control (*also see* Controls and Recorders)
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Fischer & Porter Co.
Fisher Scientific Co.
Foxboro Co.
General Electric Co.
Hach Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Ohmart Corp.
Rockwell Mfg. Co.
Wallace & Tiernan Inc.
Westinghouse Electric Corp.

Ion-Exchange Equipment
Permutit Co., Div. of Pfaudler Permutit Inc.
A. O. Smith Corp.

Jointing Materials
American Concrete Pressure Pipe Assn.
Gray Concrete Pipe Co., Inc.
Keasbey & Mattison Co.
National Clay Pipe Mfrs., Inc.
National Sewer Pipe Ltd. (Canada)
Perry-Austen Mfg. Co.
Robinson Clay Product Co.
Stebbins Engr. & Mfg. Co.

Joints, Mechanical
American Cast Iron Pipe Co.
Johns-Manville Sales Corp.
National Sewer Pipe Ltd. (Canada)
Robinson Clay Product Co.
Smith-Blair, Inc.
U. S. Pipe & Foundry Co.

Laboratory Equipment and Supplies
Filtration Equipment Corp.
Fisher Scientific Co.
General Chemical Div., Allied Chemical Corp.
Hach Co.
Stuart Corp.

Lift Stations
Davco Corp.
Smith & Loveless
Tex-Vit Mfg. Co.
Yeomans Brothers Co.

Lighting Fixtures
General Electric Co.
Westinghouse Electric Corp.

Lubricants
Homestead Valve Mfg. Co.
Johns-Manville Sales Corp.

Manhole and Inlet Castings
American-Marietta Co.
Vapor Recovery Systems Co.

Masonry Building Materials
American-Marietta Co.
Portland Cement Assn.
Price Brothers Co.

Meter Boxes
Johns-Manville Sales Corp.

Meters (Sewage, Sludge, Water, Air, and Gas)
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Ralph B. Carter Co.
Filtration Equipment Corp.
Foxboro Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Rockwell Mfg. Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Simplex Valve and Meter Co.
Worthington Corp.

Mixing Devices
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.

Motors
Chicago Pump Co.
Fairbanks, Morse & Co.
General Electric Co.
Link-Belt Co.
A. O. Smith Corp.
Westinghouse Electric Corp.
Worthington Corp.

Odor Control Materials
Airkem, Inc.
Tennessee Corp.
Wallace & Tiernan Inc.

Odor Counteractants
Airkem Inc.

Package Treatment
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Infilco Inc.
Municipal Service Co.
Smith & Loveless
Yeomans Brothers Co.

Packing
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Paints and Protective Coatings
Amercoat Corp.
Inertol Co., Inc.
Koppers Co., Inc.
Perry-Austen Mfg. Co.
Smith & Loveless
Stebbins Engr. & Mfg. Co.

Pipe, Asbestos Cement
Industrial Materials Co.
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Pipe, Cast Iron
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Industrial Materials Co.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Pipe, Clay
Industrial Materials Co.
National Clay Pipe Mfrs., Inc.
National Sewer Pipe Ltd. (Canada)
Robinson Clay Product Co.

Pipe Cleaning
Centriline Corp.
Flexible Inc.
Homestead Valve Mfg. Co.
National Water Main Cleaning Co.
W. H. Stewart, Inc.

Pipe Coatings and Linings
Amercoat Corp.
American Pipe & Construction Co.
Centriline Corp.
Koppers Co., Inc.
National Water Main Cleaning Co.
Perry-Austen Mfg. Co.
Stebbins Engr. & Mfg. Co.

Pipe, Concrete
American Concrete Pressure Pipe Assn.
American-Marietta Co.
American Pipe & Construction Co.
Gray Concrete Pipe Co., Inc.
Lock Joint Pipe Co.
National Sewer Pipe Ltd. (Canada)
Portland Cement Assn.
Price Brothers Co.

Pipe, Fiber
Sonoco Products Co.

Pipe Fittings
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Keasbey & Mattison Co.
National Sewer Pipe Ltd. (Canada)
Price Brothers Co.
Robinson Clay Product Co.
Smith-Blair, Inc.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Pipe Jointing Materials (*see* Jointing Materials)

Pipe, Plastic
Amercoat Corp.
Evanite Plastic Co.

Pipe, Repairs
Centriline Corp.
Smith-Blair, Inc.

Pipe, Steel
American Pipe & Construction Co.
Armco Drainage & Metal Products, Inc.
Keasbey & Mattison Co.
A. O. Smith Corp.

Plastic Pipe Products
Amercoat Corp.
Evanite Plastic Co.
Keasbey & Mattison Co.

Publications
American City Magazine
Engineering News-Record
Liverpool University Press (England)
Public Works Magazine
Wastes Engineering Magazine
Water & Sewage Works
John Wiley & Sons, Inc.

Pump Controls
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Chicago Pump Co.
Fischer & Porter Co.
Foxboro Co.
General Electric Co.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Rockwell Mfg. Co.
Smith & Loveless
Westinghouse Electric Corp.
Worthington Corp.
Zimmer & Francescon

PROCEEDINGS OF MEMBER ASSOCIATIONS

SOUTH DAKOTA WATER POLLUTION CONTROL ASSOCIATION

The 26th Annual Meeting of the South Dakota Water and Sewage Works Conference and the 1st Annual Meeting of the South Dakota Sections of the American Water Works Association and the Water Pollution Control Federation were held at Watertown, South Dak., Sept. 7–9, 1960. Total registration for the joint meeting was 144 and included municipal officials, water and sewage works personnel, commercial representatives, state and federal personnel, and guests.

The first subject discussed in the technical program was "Development and Use of Diverted Missouri River Water in South Dakota." The panel discussing the subject included: Charles E. Carl, Director, Division of Sanitary Engineering, South Dakota Department of Health, Pierre; M. E. Von Seggern, Chief, Project Development Division, Missouri-Oahe Projects Office, Bureau of Reclamation, Huron; Raymond Lund, District Specialist, South Dakota Water Resources Commission, Pierre; and Herbert C. Clare, Regional Program Director, Water Supply and Pollution Control Program, Region VI, Public Health Service, Kansas City, Mo. Proposed future uses of impounded water in South Dakota were discussed with particular

(*Continued on page 211a*)

Lasting Service with

DAVCO FLOODED SUCTION SEWAGE LIFT STATIONS

- Flexible Bulkhead Seals
- Flood Control Devices
- Trouble-Free Control System
- Lifelong Exterior Protection
  Superior coating with Gunite optional

The Davco Flooded Suction Sewage Lift Stations, the result of years of research and exhaustive tests, provide the most versatile and trouble-free packages available.

For further details write

DAVCO CORPORATION

P. O. BOX 270 THOMASVILLE, GEORGIA

Telephone CA 6-6458

Pumps, Airlift
Davco Corp.
Walker Process Equipment Inc.

Pumps, Chemical Feed
Proportioneers Div., B-I-F Industries

Pumps, Gas
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Sutorbilt Corp.

Pumps, Grit
Nagle Pumps, Inc.

Pumps, Sewage
Alpha Ltd. (Switzerland)
American Well Works
Aurora Pump Div., The New York Air Brake Co.
Chicago Pump Co.
Davco Corp.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Infilco Inc.
Marlow Pumps, Div. of Bell & Gossett Co.
Smith & Loveless
Sutorbilt Corp.
Wallace & Tiernan Inc.
Wemco Div., Western Machinery Co.
Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Pumps, Sludge
Alpha Ltd. (Switzerland)
American Well Works
Aurora Pump Div., The New York Air Brake Co.
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Hardinge Co., Inc.
Infilco Inc.
Komline-Sanderson Engr. Corp.
Marlow Pumps, Div. of Bell & Gossett Co.
Nagle Pumps, Inc.
Sutorbilt Corp.
Wallace & Tiernan Inc.
Wemco Div., Western Machinery Co.
Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Pumps, Vacuum
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Sutorbilt Corp.

Pumps, Water
American Well Works
Aurora Pump Div., The New York Air Brake Co.
Ralph B. Carter Co.
Chain Belt Co.
Chicago Pump Co.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Marlow Pumps, Div. of Bell & Gossett Co.
Wallace & Tiernan Inc.
Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Radiation Monitoring Equipment
Westinghouse Electric Corp.

Radios, Mobile
General Electric Co.

Recorders (*also see* Instruments, Recording, and Control)
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Fischer & Porter Co.
Fisher Scientific Co.
Foxboro Co.
General Electric Co.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Ohmart Corp.
Wallace & Tiernan Inc.

Refractory Building Materials
Carborundum Co.
Johns-Manville Sales Corp.
Robinson Clay Product Co.
Stebbins Engr. & Mfg. Co.

Safety Equipment
Vapor Recovery Systems Co.

Sampling Equipment
Chicago Pump Co.
Infilco Inc.
Lakeside Engineering Corp.

Sand, Gravel, and Stone
Graver Water Conditioning Co.

Screening Equipment
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Walker Process Equipment Inc.
Zimmer & Francescon

Sedimentation Equipment (*also see* Clarifier Equipment)
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Link-Belt Co.
Walker Process Equipment Inc.
Webster Mfg., Inc.
Yeomans Brothers Co.

Sewer Cleaning Equipment
Flexible Inc.
Homestead Valve Mfg. Co.
National Water Main Cleaning Co.
W. H. Stewart, Inc.

Sewer Inspection (*see* Inspection, Sewers)

Shredders (*also see* Comminutors and Grinders)
Alpha Ltd. (Switzerland)
Chain Belt Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Yeomans Brothers Co.

Siphons
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Pacific Flush Tank Co.
Yeomans Brothers Co.

Sludge Concentrators
Eimco Corp.
Nichols Engr. & Research Corp.

Sludge Flotation Equipment (*see* Flotation Equipment)

Sludge Handling and Control
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Jeffrey Mfg. Co.
Link-Belt Co.
Nichols Engr. & Research Corp.
Walker Process Equipment Inc.
Zimmermann Process Div. of Sterling Drug Inc.

Sludge Removal Equipment
Jeffrey Mfg. Co.
Link-Belt Co.
Webster Mfg., Inc.
Zimmermann Process Div. of Sterling Drug Inc.

Sludge Shredders
Alpha Ltd. (Switzerland)
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.

Sprockets
Chain Belt Co.
Link-Belt Co.
Webster Mfg., Inc.

Steel Pipe Products
Armco Drainage & Metal Products, Inc.

Structural Metal
Alpha Ltd. (Switzerland)

Switchgears
Alpha Ltd. (Switzerland)
General Electric Co.
Westinghouse Electric Corp.
Worthington Corp.

Tanks
Chain Belt Co.
Link-Belt Co.
Preload Co., Inc.
A. O. Smith Corp.
Stebbins Engr. & Mfg. Co.

Tools
Flexible Inc.

Transformers
Alpha Ltd. (Switzerland)
General Electric Co.
Westinghouse Electric Corp.

Trickling Filter Equipment (*see* Filter Equipment, Trickling)

Trucks and Tractors
Eimco Corp.

Turbines
Worthington Corp.

Vacuum Filters (*also see* Filters, Vacuum)
Bird Machine Co.
Dorr-Oliver Inc.
Eimco Corp.
Komline-Sanderson Engr. Corp.
Proportioneers Div., B-I-F Industries

Valves and Gates
Armco Drainage & Metal Products, Inc.
Builders-Providence Div., B-I-F Industries
Chapman Valve Mfg. Co.
DeZurik Corp.
Filtration Equipment Corp.
Homestead Valve Mfg. Co.
Industrial Materials Co.
Iowa Valve Co.
Mueller Co.
Rockwell Mfg. Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Simplex Valve and Meter Co.
A. P. Smith Mfg. Co.
Snow Gates & Valves, Inc.
Westinghouse Electric Corp.
W-K-M Div. of ACF Industries, Inc.
R. D. Wood Co.
Yeomans Brothers Co.

Vessels (*see* Tanks)

Weighing Devices
Builders-Providence Div., B-I-F Industries
Fairbanks, Morse & Co.
Fisher Scientific Co.
Wallace & Tiernan Inc.

emphasis on irrigation and municipal benefits.

The general session on Friday opened with films entitled "Underwater Reflections" and "Water Bill, U.S.A." A panel discussion on "Installation of Water and Sewage Works Systems in a Small Town" was presented by K. E. Benson, Benson & Schmitz, Engineers, Sioux Falls; and C. T. DeNeui, President of the Town Board, Chancellor. A discussion was then presented on the "Watertown Sewage Treatment Plant" by John Babcock, City Engineer, Watertown, and B. E. Schmucker, Scott Engineering Company, Watertown.

The Friday noon luncheon was highlighted by an address from Ralph E. Fuhrman, Executive Secretary, Water Pollution Control Federation. Tours were conducted on Friday afternoon of the Watertown water and sewage treatment plants. The remainder of the morning was devoted to the annual conference business meeting. Officers elected for the forthcoming year are as follows:

President: Charles R. Price, Rapid City.

Vice-President: N. A. Erickson, Sanator.

Director and Secretary-Treasurer: Don C. Kalda, Pierre.

DON C. KALDA
Secretary-Treasurer

ALABAMA WATER AND SEWAGE ASSOCIATION

The 1960 Annual Meeting of the Alabama Water and Sewage Association was held June 6–8, 1960, at Auburn University, Auburn, Ala., in conjunction with the 15th Annual Short Course School.

The first two days of the meeting were devoted to classroom and laboratory instruction. The meeting's general session was held on the third day.

(*Continued on page 213a*)

HOW LONG?

SINCE YOU MENTIONED A JOURNAL SUBSCRIPTION - MEMBERSHIP TO SOMEONE IN

- YOUR OFFICE
- YOUR ORGANIZATION
- YOUR COMMUNITY
- A NEIGHBORING COMMUNITY

Your Member Association Secretary, listed on the third left-hand page of the JOURNAL, or the Federation office, will be glad to send an application form and supply any additional information.

KEY
to
37,000 JOURNAL Pages
in
Two Short Volumes

TWENTY-YEAR INDEX to *Sewage Works Journal*, 1928–1948, Volumes 1–20, provides complete indexing for these important 20 years, with 144 pages in handsome buckram binding, $3.00.

TEN-YEAR INDEX to *Sewage and Industrial Wastes*, 1949–1958, Volumes 21–30, covers 10-year period of the successor to original Journal; 168 pages; in buckram binding to match 20-Year Index, $4.00; in heavy paper, $3.00.

Both indexes contain separate listings by author, subject, and geographical categories, along with full cross-referencing. These features make them complete and easily used references.

Send orders to the Federation office; convenient coupon provided on WPCF Publications page elsewhere in JOURNAL.

WATER POLLUTION CONTROL FEDERATION

4435 Wisconsin Avenue **Washington 16, D.C.**

Among the papers of general interest were:

"Design and Construction of Sanitary Sewers," by Paul B. Krebs, Partner, Polglaze and Basenberg, Birmingham, and Harry H. Hendon, Harry Hendon and Associates, Inc., Birmingham.

"Fluoridation of Public Water Supplies," by Sidney B. Finn, Professor of Dentistry, University of Alabama, Birmingham.

"Research Perspectives in Water Quality," by Bernard B. Berger, Chief, Water Supply and Water Pollution Research, U. S. Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

"Man in Space," by Hall V. Bartlett, Warfare Systems School, Air University, Maxwell Air Force Base.

"Experiences in Troy, Alabama. Finding and Correcting Water Losses. Cost of Operating Sewage Treatment Plants," by H. S. St. John, Utilities Manager, Troy.

The following officers were elected to serve in 1960–61:

President: Clifford C. Williams, Mobile.
Vice-President: Raymond C. Ross, Birmingham.
Treasurer: Charles D. Hart, Bessemer.
Director: John M. Bolton, Montgomery.
Secretary: E. J. Finnell, Jr., University.

E. J. FINNELL, JR.
Secretary

SWISS ASSOCIATION OF WATER AND SEWAGE PROFESSIONALS

The regular Membership Meeting of the Swiss Association of Water and Sewage Professionals was held Sept.

(*Continued on page 214a*)

Personnel Service

Classified ads will be accepted for "Personnel Available" and "Personnel Wanted" only. Rates are $1.50 per line, with minimum of $5.00. Deadline for ad copy: 10th of the month preceding the issue desired. Send ad copy to Classified Advertising Dept., Water Pollution Control Federation, 4435 Wisconsin Ave., Washington 16, D. C. Send replies to same address.

Personnel Wanted

Growing northeastern Ohio county has position open for an Assistant County Sanitary Engineer. Applicant must be graduate engineer experienced in design and inspection of water and sanitary sewerage facilities. Sewage plant operation experience desirable. Submit full resumé stating education, detailed experience record, present salary, and desired salary, in original letter to: Lake County Sanitary Engineer, 53 E. Erie St., Painesville, Ohio.

TECHNICAL EDITOR

Career opportunity as technical editor in wastewater field. Duties are primarily concerned with well-established and authoritative monthly, located in the East. Must be trained sanitary engineer having first-hand familiarity with treatment plants. Editorial experience desirable but not necessary. Editorial interest and aptitude essential. Interesting and challenging work with growing organization. Send resumé containing personal history, experience, educational record, and salary requirement to:

Box V, JOURNAL WPCF
4435 Wisconsin Avenue
Washington 16, D. C.

23–24, 1960, at Tessin, Switzerland.

Among the reports which were presented were:

"Flood Control in the Tessin Canton," by Engr. Massarotti, Lugano.

"The Clarification Plant of the Weapon Site of Monte Generi," by Engr. W. Schröter, Lucerne.

Reports by Prof. O. Jaag and Engr. D. Stauber, Zürich.

Officers for the year 1960–61 are:

President: André Kropf, Zürich.
Director: André Kropf.
Treasurer: Eduard Holinger, Liestal.
Secretary: Pierre Wildi, Zürich.

PIERRE WILDI
Secretary

Don't blindfold him!

THE AWESOME-looking instrument in the picture above is an electron microscope. Through it, a cancer researcher can observe the detail of a cancer cell—magnified 100,000 times.

The microscope costs $35,000 and was paid for by American Cancer Society funds—which support 1300 scientists, all working to find the cause of cancer, and its prevention.

Don't blindfold cancer research. Give to it. Send your contribution to CANCER, c/o your local post office.

AMERICAN CANCER SOCIETY

WPCF publications

Safety in Wastewater Works

Contains information on hazards, accident statistics, rescue methods, safe practices, and equipment. 56 pages. $0.75 to members, $1.50 to others. Order as Item MOP-1.*

Utilization of Sewage Sludge as Fertilizer

An authoritative evaluation of advantages and limitations of sludge as a soil conditioner. 120 pages. $0.75 to members; $1.25 to others. Order as Item MOP-2.*

Chlorination of Sewage and Industrial Wastes

Reviews history, development, and up-to-date technique of chlorine application. 90 pages. $1.00 to members, $1.25 to others. Order as MOP-4.*

Air Diffusion in Sewage Works

History and modern practice in design, installation, operation, and maintenance of diffuser systems and appurtenances. 75 pages. $1.00 to members, $1.25 to others. Order as Item MOP-5.*

Units of Expression for Wastes and Waste Treatment

Lists of recommended units for quantities ordinarily encountered in wastes and waste treatment. 8 pages. $0.25 to members, $0.50 to others. Order as Item MOP-6.*

Sewer Maintenance

A guide for maintaining a municipal or industrial drainage system in serviceable condition. 64 pages. $1.00 to members; $1.50 to others. Order as Item MOP-7.*

Sewage Treatment Plant Design

Prepared jointly by the Federation and ASCE. Detailed presentation of the subject. 375 pages. $3.50 to members; $7.00 to others. Order as Item MOP-8.*

Design and Construction of Sanitary and Storm Sewers

Prepared jointly by the Federation and ASCE. Detailed presentation of the subject. 283 pages. $3.50 to members; $7.00 to others. Order as Item MOP-9.*

Twenty-Year Index to *Sewage Works Journal*

Covers *Sewage Works Journal*, 1928-1948. Author, subject, and geographic. 144 pages. Buckram bound, $3.00. Order as Item Dex-20.

Ten-Year Index to *Sewage and Industrial Wastes*

Covers *Sewage and Industrial Wastes*, 1949-1958. Author, subject, and geographic. 168 pages. Buckram, $4.00, heavy paper, $3.00. Order as Item Dex-10.

Glossary—Water and Sewage Control Engineering

Prepared jointly by the Federation, ASCE, AWWA, and APHA. 2,600 terms pertaining to nomenclature. 274 pages. $1.00. Order as Item Gl.

Binder

Multiple wire, 2-in. capacity, for all MOP's listed except 8 and 9. $2.00. Order as Item Bi.*

*** Discount of 15% on orders for 12 or more of any one manual.**

Water Pollution Control Federation
4435 Wisconsin Avenue, Washington 16, D. C.

Item	Copies	Cost	Item	Copies	Cost	Item	Copies	Cost
MOP-1			MOP-6			Bi		
MOP-2			MOP-7			Dex-20		
MOP-4			MOP-8			Dex-10		
MOP-5			MOP-9			Gl		

Enclosed is remittance for $

Print Name

Address

City Zone State

Member Association

If an invoice is necessary, postage will be added. Checks may be made payable to WPCF.

NEW MANUAL AVAILABLE

M. O. P. #9 — SEWER DESIGN AND CONSTRUCTION

Several years of joint effort between the Water Pollution Control Federation and the Sanitary Engineering Division of the American Society of Civil Engineers have produced a major addition to the "Manuals of Practice" series. "Design and Construction of Sanitary and Storm Sewers" has been designated M. O. P. #9.

This illustrated, 12-chapter manual of 283 pages includes detailed coverage of project planning, investigations, hydraulics, design, construction materials and methods, specifications, structural requirements of storm and sanitary sewers, and pumping stations.

A convenient order form for this and other publications appears elsewhere in this issue. The manual is $7 per copy postpaid if remittance is with order. Federation members may purchase the manual for $3.50.

WATER POLLUTION CONTROL FEDERATION

4435 Wisconsin Avenue **Washington 16, D.C.**

PROFESSIONAL SERVICES

ALBRIGHT & FRIEL, INC.
CONSULTING ENGINEERS

Water Sewage, Industrial Wastes and Incineration Problems
City Planning, Highways, Bridges and Airports
Dams, Flood Control, Industrial Buildings
Investigations, Reports, Appraisals and Rates

THREE PENN CENTER PLAZA
PHILADELPHIA 2, PA.

ALVORD, BURDICK & HOWSON
Engineers
Charles B. Burdick Louis R. Howson
Donald H. Maxwell

Water Works, Water Purification, Flood Relief, Sewerage, Sewage Disposal, Drainage, Appraisals, Power Generation

Civic Opera Building **Chicago**

ANDERSON-NICHOLS & Company
Consulting Engineers
Water Supply, Distribution and Treatment, Industrial Waste Treatment, Sewage Collection and Disposal, Refuse Collection and Disposal, Drainage, Highways and Bridges.

Hartford, Conn. Boston 14

JOHN J. BAFFA
Consulting Engineer
Sewerage & Sewage Treatment
Industrial Wastes Treatment
Design Plans & Specifications
Investigations & Rate Studies

75 West Street **New York 6, N. Y.**

MICHAEL BAKER, JR., Inc.
Consulting Engineers
Civil Engineers, Planners, and Surveyors
Municipal Engineers—Airport Design—Sewage Disposal Systems—Water Works Design and Operation—Surveys and Maps—City Planning—Highway Design—Construction Surveys—Pipe Line Surveys

Home Office: Rochester, Pa.
Branch Offices: Jackson, Miss. Harrisburg, Pa.

BAXTER AND WOODMAN
Civil and Sanitary Engineers
Water Supplies Water Treatment
Sewer Systems Sewage Treatment
Industrial Waste Treatment
Investigations

P. O. Box 166 **Crystal Lake, Illinois**

THOMAS W. BEAK
Consulting Biologist
Pollution Studies
Stream and Lake Surveys
Toxicity Tests
Biological and Chemical Analyses

Amherst View, Collins Bay, Kingston, Ontario, Canada

HOWARD K. BELL
Consulting Engineers, Inc.
WATER WORKS SWIMMING POOLS
INDUSTRIAL WASTES DRAINAGE
SEWERAGE GARBAGE DISPOSAL
VALUATIONS — RATES — REPORTS
OPERATION SUPERVISION

553 S. LIMESTONE ST., LEXINGTON, KY.

A PROFESSIONAL CARD
presents your services to over 10,000 paid readers with each issue of the JOURNAL. This is where potential clients seek professional assistance.

THIS SINGLE CARD COSTS ONLY $75 FOR 12 ISSUES

BENHAM ENGINEERING COMPANY
Consulting Engineers
215 N.E. 23rd Oklahoma City
Established 1909

It pays to secure competent and experienced professional advice!

BETZ LABORATORIES, INC.
Consulting Engineers
Industrial Waste
Industrial Water
Analysis — Design
Investigations — Operation
Gillingham & Worth Sts. — Philadelphia 24, Pa.

BLACK, CROW AND EIDSNESS
INCORPORATED
ENGINEERS
Water, sewerage, power, hydrology, recalcination, waste treatment, valuation, special investigations and reports, laboratory services
700 S.E. Third Street — Gainesville, Florida

BLACK & VEATCH
Consulting Engineers
Sewage – Gas – Water – Electricity – Industry
Reports, Design, Supervision of Construction, Investigations, Valuation and Rates
1500 Meadow Lake Parkway
Kansas City 14, Mo.

CLINTON BOGERT ENGINEERS
Consultants
CLINTON L. BOGERT — IVAN L. BOGERT
DONALD M. DITMARS — ROBERT A. LINCOLN
CHARLES A. MANGANARO — WILLIAM MARTIN
Water & Sewage Works — Incinerators
Drainage — Flood Control
Highways and Bridges — Airfields
145 East 32nd Street, New York 16, N. Y.

BOWE, ALBERTSON & ASSOCIATES
Engineers
Water and Sewage Works
Industrial Wastes
Refuse Disposal
Valuations
Laboratory Service
75 West St. — 1000 Farmington Ave.
New York 6, N.Y. — West Hartford 7, Conn.

BOYLE ENGINEERING
Consulting Engineers
Water — Sewers — Streets
Structures — Surveys
Reports—Special Districts
331 Spurgeon Bldg. — 3913 Ohio, Rm. 200
Santa Ana, Calif. — San Diego 4, Calif.

BROWN AND CALDWELL
CIVIL AND CHEMICAL ENGINEERS
WATER - SEWAGE - INDUSTRIAL WASTE
CONSULTATION - DESIGN - OPERATION
CHEMICAL AND BACTERIOLOGICAL LABORATORIES
66 MINT STREET — SAN FRANCISCO 3

CHECK HERE
Whenever You Need
Professional Advice

FLOYD G. BROWNE AND ASSOCIATES
CONSULTING ENGINEERS
Water Supply — Purification — Sewerage — Sewage Treatment — Power and Industrial Plants — Industrial Waste Treatment and Disposal
Reports — Designs — Supervision — Operation
125 West Church Street — Marion, Ohio

BUCK, SEIFERT AND JOST
Consulting Engineers
Specializing in Sewerage and Sewage Disposal, Water Supply and Water Purification, Valuations and Reports
Chemical and Biological Laboratories
112 East 19th Street — New York 3, N. Y.

ONLY $75
for 12 ads, plus complimentary JOURNALS during your series. A card presents your services to the largest group of prospective clients in the wastewater field.

Take advantage of the services of these outstanding firms!

BURGESS & NIPLE
Consulting Engineers
Established 1908
Sewage and industrial wastes disposal
Investigations, reports, design, rates
Laboratories, Plant Supervision
2015 W. Fifth Ave. Columbus 12, Ohio

PROFESSIONAL SERVICES

BURNS & McDONNELL
Engineers - Architects - Consultants
P.O. Box 173
Kansas City 41, Missouri

CAMP, DRESSER and McKEE
Consulting Engineers
Water Works and Water Treatment
Sewerage and Sewage Treatment
Municipal and Industrial Wastes
Investigations and Reports
Design and Supervision
Research and Development
Flood Control
18 Tremont Street Boston 8, Mass.

Capitol Engineering Corporation
Consulting Civil Engineers
Dillsburg, Pennsylvania, U.S.A.

JOHN A. CAROLLO
Consulting Engineers
Water Supply and Purification, Sewerage, Sewage Treatment, Industrial Wastes, Power Generation, Streets.
3308 N. Third St. Phoenix, Arizona
2168 Shattuck Ave. Berkeley 4, Calif.

THE CHESTER ENGINEERS
Water Supply and Purification
Sewage Treatment
Industrial Waste Disposal and Recovery
Power Plants–Incineration–Gas Systems
Valuations–Rates–Management
Laboratory
601 Suismon St., Pittsburgh 12, Penna.

CONSOER, TOWNSEND & ASSOCIATES
Consulting Engineers
Sewage treatment, sewers, storm drainage, flood control—Water supply and treatment—Highway and bridges—Airports—Urban renewal—Electric and gas transmission lines—Rate studies, surveys and valuations—Industrial and institutional buildings.
360 East Grand Ave. Chicago 11, Ill.

CRAWFORD, MURPHY & TILLY
Consulting Engineers
TRAFFIC PROBLEMS—SWIMMING POOLS—SEWERS
SEWAGE TREATMENT—WASTES TREATMENT
WATER WORKS—RESERVOIRS—DRAINAGE
FLOOD CONTROL—AIRPORTS—STREETS
HIGHWAYS—EXPRESSWAYS—SURVEYS & REPORTS
755 South Grand West Springfield, Illinois

Damon & Foster
Consulting Civil Engineers and Surveyors
Sewerage, Sewage Disposal, Water Supply, Surveys, Land Subdivision, City and Town Planning, Reports, Design, Supervision
Sharon Hill, Pennsylvania

DOW INDUSTRIAL SERVICE
Division of The Dow Chemical Company
Consulting Laboratories
Pollutional Characteristics — Waste Evaluations
Treatment Process Development
Chemical Cleaning
20575 Center Ridge Road
Cleveland 16, Ohio

JOURNAL
Advertising Pages
These pages provide assistance to you when service is needed in the wastewater field. The WPCF Product Guide, in the final pages of the JOURNAL, also assist the readers.

Consult these specialists for professional assistance!

PROFESSIONAL SERVICES

ONLY $75 PER YEAR

is the cost of a professional listing in this space. A card here will identify your firm with the specialized sewage and industrial wastes field and will afford maximum prestige!

FAY, SPOFFORD & THORNDIKE, INC.
ENGINEERS
Sewage Treatment—Sewerage and Drainage Systems
Water Supply and Distribution—Incinerators
Airports—Bridges—Express Highways—Port and Terminal Works—Industrial Buildings
11 Beacon Street **Boston 8, Massachusetts**

FINKBEINER, PETTIS & STROUT
CONSULTING ENGINEERS
Water Supply, Water Treatment,
Sewerage, Sewage Treatment,
Industrial Waste Treatment
2130 Madison Avenue **Toledo 2, Ohio**

FROMHERZ ENGINEERS
Structural - Civil - Municipal
Four Generations Since 1867
Water Supply; Sewerage; Structures; Drainage; Foundations
Industrial Waste Disposal
Investigations; Reports; Plans and Specifications; Supervision
816 Howard Avenue **New Orleans 12, La.**

A PROFESSIONAL CARD
presents your services to over 10,000 paid readers with each issue of the JOURNAL. This is where potential clients seek professional assistance.
THIS SINGLE CARD COSTS ONLY $75 FOR 12 ISSUES

GANNETT FLEMING CORDDRY AND CARRPENTER, INC.
Engineers
Sewage, Industrial Wastes & Garbage Disposal, Dams, Water Works, Highways, Bridges & Airports, Traffic & Parking—Appraisals, Investigations & Reports.
HARRISBURG, PENNSYLVANIA
Branch Offices
Pittsburgh, Pa. **Philadelphia, Pa.** **Daytona Beach, Fla.**

GIBBS & HILL, INC.
Consulting Engineers
Industrial and Municipal Waste Treatment
Water Supply and Treatment
Electric Power and Transmission
Transportation and Communication
PENNSYLVANIA STATION
NEW YORK 1, NEW YORK

GILBERT ASSOCIATES, INC.
Engineers and Consultants
Water Supply and Purification
Sewage and Industrial Waste Treatment
Chemical Laboratory Service
Investigations and Reports
New York **P.O. Box 1498 READING, PA.** **Washington**

GREELEY & HANSEN
Engineers
Water Supply, Water Purification
Flood Control, Drainage, Refuse Disposal
Sewerage, Sewage Treatment
14 East Jackson Boulevard, Chicago 4, Illinois

HOWARD R. GREEN CO.
Consulting Engineers
Established 1913
H. R. GREEN
C. D. MULLINEX — G. R. HOTCHKISS
J. A. SAMPSON — H. A. MILLER
G. C. AHRENS — B. W. GRIFFITH
Water, Sewerage & Industrial Wastes
Public Works & Industrial Projects
Green Engineering Building **Cedar Rapids, Iowa**

Take advantage of the services of these outstanding firms!

Charles W. Greengard Associates
Consulting Engineers
Sewage Treatment, Sewerage, Drainage, Water Supply, Industrial Waste Treatment, Roads, Subdivisions, Investigations, Reports, Designs and Supervision
Deerfield, Illinois

PROFESSIONAL SERVICES

L. B. GRIFFITH
CONSULTING ENGINEER
Research, Reports and Designs on Sewage and Industrial Waste Treatment.
450 West Broad St. **Falls Church, Va.**

HASKINS, SHARP & ORDELHEIDE
CONSULTING ENGINEERS
Water—Sewage & Industrial Wastes—Hydraulics
Reports, Design, Supervision of Construction
Appraisals, Valuations, Rate Studies
1009 Baltimore Ave. **Kansas City 5, Mo.**

HAVENS AND EMERSON
A. A. Burger — A. M. Mock
J. W. Avery — F. S. Palocsay
E. S. Ordway — G. H. Abplanalp
S. H. Sutton
Frank C. Tolles, Consultant
Consulting Engineers
WATER, SEWERAGE, GARBAGE, INDUSTRIAL WASTES, VALUATIONS—LABORATORIES
Leader Bldg. **Cleveland 14, Ohio** — **Woolworth Bldg.** **New York 7, N. Y.**

HAZEN AND SAWYER
ENGINEERS
RICHARD HAZEN — ALFRED W. SAWYER
H. E. HUDSON, JR.
Water and Sewage Works
Industrial Waste Disposal
Drainage and Flood Control
360 Lexington Ave., **New York 17, N. Y.**

ANGUS D. HENDERSON
Consulting Engineers
ANGUS D. HENDERSON — THOMAS J. CASEY
Water Supply and Sanitation
330 Winthrop St., Westbury, New York
355 Knollwood Ave., Douglaston, L. I., New York

HENNINGSON, DURHAM & RICHARDSON
Consulting Engineers and Architects since 1917 for more than 700 cities and towns
Water Works, Light and Power, Sewers, Sewage Treatment, Reports, Flood Control, Appraisals, Drainage, Industrial Works
Omaha • Colorado Springs • Phoenix • Dallas

HORNER & SHIFRIN
Consulting Engineers
E. E. BLOSS — V. C. LISCHER
Airports, Sewerage & Drainage, Hydrology, Sewage Treatment, Industrial Waste Treatment, Water Supply & Treatment, Paving, Structures, Industry Engineering Services
1221 Locust Street **St. Louis 3, Mo.**

George E. Hubbell — Albert Roth — Homer W. Clark
Theodore G. Biehl — George S. Roth — James W. Hubbell
HUBBELL, ROTH & CLARK, INC.
Consulting Engineers
Sewage and Industrial Waste Treatment
Sewerage and Drainage Systems
954 N. Hunter Blvd. **Birmingham, Michigan**

GRIT AND HEAVY SLUDGE REMOVAL
CONCRETE RESTORATION
SEWAGE AND WATER WORKS
HUDSON-RUMSEY CO., INC.
Professional Engineers
1679 Niagara St.
Buffalo 7, N. Y.

It pays to secure competent and experienced professional advice!

PROFESSIONAL SERVICES

WILLIAM T. INGRAM
Consulting Engineer
Sanitary and Public Health Engineering
Planning—Design—Research—Water
Sewage—Refuse—Industrial Wastes
Air Pollution Control—Industrial Health
Offices:
East Coast — 20 Point Crescent, Whitestone 57, N.Y.
West Coast — 90 Panoramic Way, Walnut Creek, Calif.

The Jennings-Lawrence Co.
Civil and Municipal Engineers
Consultants
Water Supply, Treatment & Distribution
Sewers & Sewage Treatment
Reports—Design—Construction
1392 King Ave. Columbus 12, Ohio

JOHNSON & ANDERSON, INC.
Consulting Engineers
Sewerage—Water Supply & Distribution—Bridges
Highways—Municipal Engineering—Flood Control & Drainage
2300 Dixie Hwy., Pontiac, Mich. FE 2-0181
Warren Office: 24187 Ryan Rd., Warren, Mich., SLocum 7-1167
Flint Office: 604 Metropolitan Bldg., Flint, Mich., CEdar 9-4102

JONES, HENRY & WILLIAMS
Consulting Engineers
Water Works
Sewerage & Treatment
Waste Disposal
2000 West Central Ave. Toledo 6, Ohio

KENNEDY ENGINEERS
COMPLETE ENGINEERING SERVICE
Investigations, Reports, Design
Supervision of Construction and Operation
Sewerage, Sewage Treatment and Industrial Waste Disposal
Chemical and Biological Laboratory
604 MISSION ST., SAN FRANCISCO 5
Los Angeles — Salt Lake City — Tacoma

KIRKHAM, MICHAEL & ASSOCIATES
ENGINEERS - ARCHITECTS
Complete Municipal & Industrial Services: Investigations, Reports, Design, Supervision of Construction, Rates
WATER — SEWAGE & WASTES
STREETS — AIRPORTS — BRIDGES & STRUCTURES
Omaha, Neb. — 508 South 19th St.
Rapid City, S. D. — 519 Kansas City St.
Fargo, N. D. — 802 Sixth Avenue North

MORRIS KNOWLES Inc.
Engineers
Water Supply and Purification, Sewerage and Sewage Disposal, Valuations, Laboratory, City Planning.
1312 Park Bldg. Pittsburgh 22, Pa.

KOEBIG AND KOEBIG
Consulting Engineers Since 1910
Investigations, Reports, Designs
Sewerage & Sewage Treatment
Water Supply & Water Treatment
Municipal Engineering
3242 West 8th Street, Los Angeles 5, Calif.

LANNING
Sanitary Engineering Co., Inc.
Consulting Engineers
Water, Sewage, Drainage, and Industrial Wastes
Reports, Designs, Supervision Of Construction and Operation
Chemical & Biological Laboratory
1100 South Broad St. Trenton, N. J.

LOCKWOOD, KESSLER & BARTLETT, INC.
CONSULTING ENGINEERS
Water, Sewage, Industrial Wastes, Incinerators, Water Pollution Studies, Municipal Engineering, Aerial Mapping, Highways, and Bridges
Syosset, New York - San Juan, Puerto Rico
Bogota, Colombia

ONLY $75
for 12 ads, plus complimentary JOURNALS during your series. A card presents your services to the largest group of prospective clients in the wastewater field.

Consult these specialists for professional assistance!

Lozier Consultants, Inc.
Engineers
Sewerage, Sewage Disposal, Water Supply, Water Purification, Refuse Disposal
10 Gibbs Street — Rochester 4, N. Y.

CHARLES A. MAGUIRE & ASSOCIATES
Engineers
Sewage Collection and Disposal
Water Supply and Distribution
Drainage, Refuse and Pipelines
14 Court Square — Boston 8, Mass.
1100 Turks Head Building — Providence 3, R. I.

CHAS. T. MAIN, INC.
Consulting Engineers Since 1893
STUDIES • DESIGNS • CONSTRUCTION MANAGEMENT
REPORTS • VALUATIONS
Water Supply and Treatment • Sewerage
Sewage Disposal • Industrial Waste Treatment
BOSTON, MASSACHUSETTS • CHARLOTTE, N. CAROLINA

GEORGE B. MEBUS, Inc.
Consulting Engineers
Water Supply — Sewage Treatment
Industrial Waste Treatment
BROAD STREET TRUST BUILDING
GLENSIDE, PA.

METCALF & EDDY
ENGINEERS
Soils, Foundations, Waterworks, Sewage Works, Drainage, Irrigation, Flood Control, Refuse, Industrial Wastes, Airports, Highways, Military Projects, Industrial and Commercial Facilities.
Statler Building, Boston 16, Massachusetts

JAMES M. MONTGOMERY
Consulting Engineers, Inc.
Water Supply—Water Purification
Sewerage—Sewage and Waste Treatment
Flood Control—Drainage
Valuations—Rates
Investigations—Design—Operation
535 E. Walnut St. — Pasadena, Calif.

Nussbaumer, Clarke & Velzy, Inc.
Consulting Engineers
SEWAGE TREATMENT—WATER SUPPLY
INCINERATION—DRAINAGE
INDUSTRIAL WASTE TREATMENT
APPRAISALS
327 Franklin St., Buffalo, N. Y.
500 Fifth Ave., New York 36, N. Y.

O'BRIEN & GERE
Consulting Engineers
Industrial Waste Treatment
Industrial and Municipal Water Supply
Sewerage and Sewage Treatment
400 East Genesee St. — Syracuse 2, New York

PARSONS, BRINCKERHOFF, QUADE & DOUGLAS
Civil and Sanitary Engineers
Water, Sewage, Drainage and Industrial Waste Problems.
Structural — Power — Transportation
165 Broadway — New York 6, N.Y.

PIATT & DAVIS AND ASSOCIATES
P. D. DAVIS — W. M. PIATT, III
Consulting, Designing, and Supervising Engineers
Water Works, Sanitary Sewers, Water Purification
Sewage Treatment, Streets, Power Plants
Electrical Distribution, Reports and Appraisals
One Eleven Corcoran St. Bldg. — Durham, N. C.

MALCOLM PIRNIE ENGINEERS
Malcolm Pirnie — Carl A. Arenander
Ernest W. Whitlock — Malcolm Pirnie, Jr.
Robert D. Mitchell — Alfred C. Leonard
MUNICIPAL AND INDUSTRIAL
Water Supply - Water Treatment
Sewage and Waste Treatment
Drainage - Rates - Refuse Disposal
25 West 43rd Street, New York 36, N. Y.
3013 Horatio Street, Tampa 9, Florida

LEE T. PURCELL
Consulting Engineer
Water Supply & Purification; Sewerage & Sewage Disposal; Industrial Wastes; Investigations & Reports; Design; Supervision of Construction & Operation
Analytical Laboratories
36 De Grasse St. — Paterson 1, N. J.

It pays to secure competent and experienced professional advice!

RADER AND ASSOCIATES
Engineers and Architects
Water Works, Sewers, Refuse Disposal and Other Public Works Engineering Reports, Investigations, Consultations, Plans, Specifications and Supervision of Construction Work
The First National Bank Building, Miami 32, Florida

REAVES & GREGORY
Consulting Engineers
PAUL C. REAVES
PAUL D. GREGORY
3332 West Seventh **Fort Worth 7, Texas**

REYNOLDS, SMITH AND HILLS
ENGINEERING DIVISION
RS&H
Planning • Reports
Design • Supervision
BOX 4817 · JACKSONVILLE 1, FLORIDA

THOMAS M. RIDDICK & ASSOCIATES
Consulting Engineers and Chemists
Municipal and Industrial Water Purification, Sewage Treatment Plant Supervision, Industrial Waste Treatment
Laboratories for Chemical and Bacteriological Analyses
369 E. 149th St. **New York 55, N.Y.**
MOtt Haven 5-2424

RIPPLE AND HOWE, Inc.
Consulting Engineers
V. A. VASEEN
Appraisals—Reports
Design—Supervision
Water Works Systems, Filtration and Softening Plants, Reservoirs and Dams, Sanitary and Storm Sewers, Sewage Treatment Plants, Refuse Disposal, Airports
2747 Zuni Street **Denver 11, Colorado**

ROBERT AND COMPANY
ASSOCIATES
ARCHITECTS AND ENGINEERS
ATLANTA

RUSSELL AND AXON
Consulting Engineers
Civil — Sanitary — Structural
Industrial — Electrical
Rate Investigations
408 Olive St., **Municipal Airport**
St. Louis 2, Mo. **Daytona Beach, Fla.**

TRUMAN SCHLUP
CONSULTING ENGINEER
Highways, Structures, Water, Sewerage
Reports, Design
Investigations, Supervision of Construction
1401 Fairfax Trafficway **Kansas City, Kans.**

SERVIS, VAN DOREN & HAZARD
Engineers-Architects
Investigations · Design · Supervision of Construction · Appraisals
Water · Sewage · Streets · Expressways · Highways
Bridges · Foundations · Airports · Flood Control
Drainage · Aerial Surveys · Site Planning · Urban Subdivisions · Industrial Facilities · Electrical Mechanical
2910 Topeka Blvd. **Topeka, Kansas**

J. E. SIRRINE COMPANY
Engineers Since 1902
GREENVILLE, SOUTH CAROLINA
Design, Reports, Consultations
Water Supply and Treatment
Sewage and Industrial Waste Treatment
Stream Pollution Surveys
Chemical and Bacteriological Analyses

SMITH and GILLESPIE
Consulting Engineers
All types of
Municipal Public Works & Utilities
Complete Services
P. O. Box 1048, Jacksonville, Fla.

John R. Snell
ENGINEERS
Inc. 221 N. Cedar ■ Lansing, Mich. ■ IVanhoe 4-9493
Water Purification ■ Water Supply ■ Sewerage Systems ■ Sewage Treatment ■ Refuse Collection ■ Composting ■ Incineration ■ Urban Planning ■ Industrial Waste ■ Bridges and Streets ■ Soils and Foundations ■ Research and Development

It pays to secure competent and experienced professional advice!

STANLEY ENGINEERING COMPANY
Consulting Engineers
Hershey Building, Muscatine, Iowa
208 S. LaSalle Street, Chicago 4, Illinois
Hanna Building, Cleveland 15, Ohio

PROFESSIONAL SERVICES

ALDEN E. STILSON & ASSOCIATES
Limited
Consulting Engineers
Water Supply—Sewerage—Waste Disposal
Bridges—Highways—Industrial Buildings
Studies—Surveys—Reports
245 N. High St. Columbus 15, Ohio

TIGHE & BOND
CONSULTING ENGINEERS
Bowers and Pequot Streets
Holyoke, Massachusetts
Tel. JEfferson 3-3991
Civil, Sanitary and Electrical Engineering
Investigations, Reports, Plans and Specifications
Supervision of Construction and Operation

WALLACE & HOLLAND
Consulting Engineers
Civil — Sanitary — Structural
401 N. Federal Mason City, Iowa

J. STEPHEN WATKINS
J. S. Watkins G. R. Watkins
CONSULTING ENGINEERS
Municipal and Industrial Engineering. Water Supply and Purification, Sewerage and Sewage Treatment, Highways and Structures, Reports, Investigations and Rate Structures.
446 East High Street Lexington, Kentucky
Branch Office
4726 Preston Highway Louisville, Kentucky

LEONARD S. WEGMAN CO.
Consulting Engineers
Water, Sewerage and Drainage Works
Incinerators
Sanitary, Industrial Wastes—Treatment, Recovery
Erosion, Flood and Waterfront Works
Reports — Design — Supervision
235 East 45th St. New York 17, N. Y.

ROY F. WESTON, INC.
Engineers—Biologists—Chemists
Industrial Wastes
Stream Pollution—Air Pollution
Water—Sewage
Surveys—Research—Development—Process Engineering — Plans and Specifications — Operation Supervision — Analyses — Evaluations and Reports
Newtown Square Pennsylvania

WESTON & SAMPSON
Consulting Engineers
Water Supply Water Purification
Corrosion Control
Sewerage, Sewage and Industrial Wastes Treatment
Stream Pollution Studies
Supervision, Valuation
Laboratory
14 Beacon Street Boston 8, Mass.

WHITMAN & HOWARD
Engineers (Est. 1869)
Sewerage, Sewage Disposal, Municipal and Industrial Development Problems, Water Supply, Water Purification, Water Front Improvements, Investigations, Reports, Designs, Supervision, Valuations
89 Broad Street, Boston, Mass.

WHITMAN, REQUARDT & ASSOCIATES
Engineers—Consultants
Civil — Sanitary — Structural
Mechanical — Electrical
Reports, Plans, Supervision, Appraisals
1304 St. Paul Street Baltimore 2, Maryland

WILSON & COMPANY
ENGINEERS & ARCHITECTS
Investigations — Planning — Design
Water, Sewerage, Streets, Highways, Bridges, Electrical, Airfields, Drainage, Dams, Treatment Plants, Industrial Installations
Chemical Testing Lab — Aerial Mapping
Electronic Computer Services, Reproductions
631 East Crawford - - Salina, Kansas
2930 Geo. Washington Ave., Wichita, Kansas

Consult these specialists for professional assistance!

INDEX TO ADVERTISERS

(See pages 204a, 206a, 208a, and 210a for full listing of products.)

	Page
Amercoat Corporation	198a
B-I-F Industries, Incorporated	Second Cover
Cast Iron Pipe Research Association	190a, 191a
Chicago Pump Company	Facing Second Cover
Davco Corporation	209a
Dorr-Oliver Incorporated	202a
Eimco Corporation	186a, 187a
Evanite Plastic Company (Division of The Evans Pipe Company)	193a
Filtration Equipment Corporation	194a
Fischer and Porter Company	181a
Flexible Incorporated	189a
General Chemical Division (Allied Chemical Corporation)	192a
Gorman-Rupp Company	200a
Infilco Incorporated	183a
Johns-Manville Sales Corporation	201a
Lock Joint Pipe Company	Third Cover
National Clay Pipe Manufacturers, Incorporated	195a
Nichols Engineering and Research Corporation	179a
Pacific Flush Tank Company	177a
Pfaudler Permutit Incorporated	199a
Robinson Clay Product Company	197a
Tex-Vit Manufacturing Company	188a
United States Pipe and Foundry Company	184a, 185a
Vapor Recovery Systems Company	203a
Walker Process Equipment Incorporated	Facing Third Cover
Wallace and Tiernan Incorporated	Fourth Cover

PROFESSIONAL SERVICES, 217a–225a

Albright & Friel, Inc.
Alvord, Burdick & Howson
Anderson-Nichols & Co.
Baffa, John J.
Baker, Michael, Jr., Inc.
Baxter and Woodman
Beak, Thomas W.
Bell, Howard K.
Benham Engineering Co.
Betz Laboratories, Inc.
Black, Crow and Eidsness Inc.
Black & Veatch
Bogert, Clinton, Engineers
Bowe, Albertson & Associates
Boyle Engineering
Brown and Caldwell
Browne, Floyd G., and Associates
Buck, Seifert and Jost
Burgess & Niple
Burns & McDonnell
Camp, Dresser and McKee
Capitol Engineering Corp.
Carollo, John A.
Chester Engineers, The
Consoer, Townsend & Associates
Crawford, Murphy & Tilly
Damon & Foster
Dow Industrial Service
Fay, Spofford & Thorndike, Inc.
Finkbeiner, Pettis & Strout
Fromherz Engineers
Gannett Fleming Corddry & Carpenter, Inc.
Gibbs & Hill, Inc.
Gilbert Associates, Inc.
Greeley & Hansen
Green, Howard R., Co.
Greengard, Charles W., Associates
Griffith, L. B.
Haskins, Sharp & Ordelheide
Havens and Emerson
Hazen and Sawyer
Henderson, Angus D.
Henningson, Durham & Richardson, Inc.
Horner & Shifrin
Hubbell, Roth & Clark, Inc.
Hudson-Rumsey Co., Inc.
Ingram, William T.
Jennings-Lawrence Co.
Johnson & Anderson, Inc.
Jones, Henry & Williams
Kennedy Engineers
Kirkham, Michael & Associates
Knowles, Morris, Inc.
Koebig and Koebig
Lanning Sanitary Engineering Co., Inc.
Lockwood, Kessler & Bartlett, Inc.
Lozier Consultants, Inc.
Maguire, Charles A., & Associates
Main, Chas. T., Inc.
Mebus, George B., Inc.
Metcalf & Eddy
Montgomery, James M.
Nussbaumer, Clarke & Velzy, Inc.
O'Brien & Gere
Parsons, Brinckerhoff, Quade & Douglas
Piatt & Davis and Associates
Pirnie, Malcolm, Engineers
Purcell, Lee T.
Rader and Associates
Reaves & Gregory
Reynolds, Smith and Hills
Riddick, Thomas M., & Associates
Ripple and Howe, Inc.
Robert and Company Associates
Russell and Axon
Schlup, Truman
Servis, Van Doren & Hazard
Sirrine, J. E., Co.
Smith and Gillespie
Snell, John R., Engineers, Inc.
Stanley Engineering Co.
Stilson, Alden E., & Associates
Tighe & Bond
Wallace & Holland
Watkins, J. Stephen
Wegman, Leonard S., Co.
Weston, Roy F., Inc.
Weston & Sampson
Whitman & Howard
Whitman, Requardt & Associates
Wilson & Company

PATRONIZE OUR ADVERTISERS—whose support makes possible the publication of this journal. *When writing advertisers be sure to mention JOURNAL of the WATER POLLUTION CONTROL FEDERATION.*

NEW MANUAL AVAILABLE

M. O. P. 7—SEWER MAINTENANCE

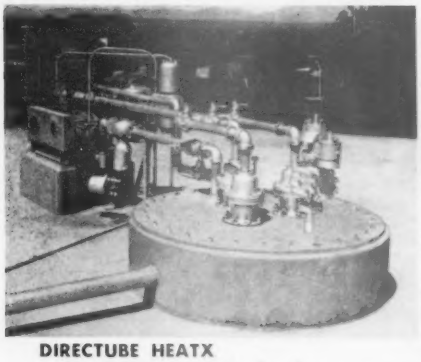
- complete coverage for protecting a $15 billion investment
- a *first* in the field
- 64 pages
- 68 references
- $1.00 to members; $1.50 to others
- see coupon on WPCF Publications page in back of JOURNAL

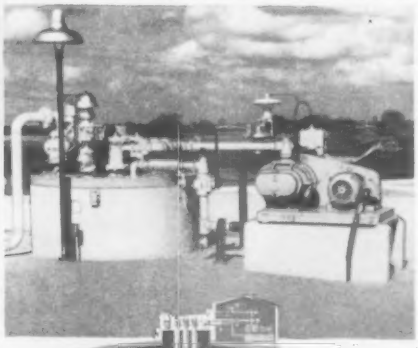
WATER POLLUTION CONTROL FEDERATION

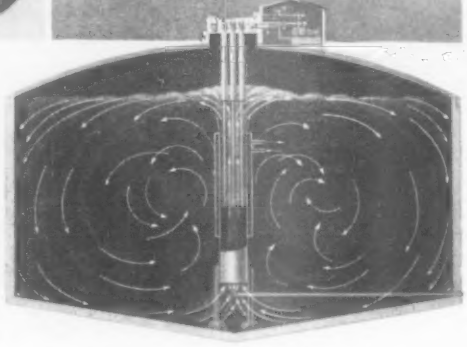
4435 Wisconsin Avenue Washington 16, D.C.

complete homogenizing

GASLIFTER DIGESTER CIRCULATOR-MIXER







DIRECTUBE HEATX
— for economical sludge heating

GAS LOCKING CHAMBER
— for safe, easy inspection

GAS-LIFT PRINCIPLE
— for powerful over-all stirring

All Gaslifter equipped digesters have the common advantage of better, uniform digestion. Contents are liquefied, completely circulated and diffused — even dense sludges, surface grease and scum. Bottom shoals eliminated. The eductor tube, gas-lift principle creates a powerful over-all roll within the digester which sweeps all areas resulting in complete homogenizing.

Positive, powerful roll allows for economical intermittent operation since steady state homogenization takes place within 15 minutes.

Rapid gasification is induced while volatile acids remain low.

Incoming green sludge is readily admixed so as to accelerate its digestion permitting maximum loading. Methane yield is increased and good supernatent obtained.

Built-in gas locking chamber permits safe withdrawal of the gas diffuser from within the lift tube without digester shut-down or danger.

The DIRECTUBE HEATX-GASLIFTER assembly combines economical, positive temperature control and efficient digester operation. DIRECTUBE HEATX is shop fabricated as an integral part of the GASLIFTER and requires only hot water recirculation lines from a Walker Sewage Gas Boiler. Optimum temperature requirements are easily maintained. Available with manual or automatic controls.

Write for bulletins 24-S-82 and 25-S-91.

Top Left — LAS CRUCES, N.M. — 8000 gpm GAS-LIFTER in 50' dia. digester with fixed cover. R. A. Smith, Supt. Gordon Herkenhoff & Assoc., Albuquerque, Cons. Engrs.

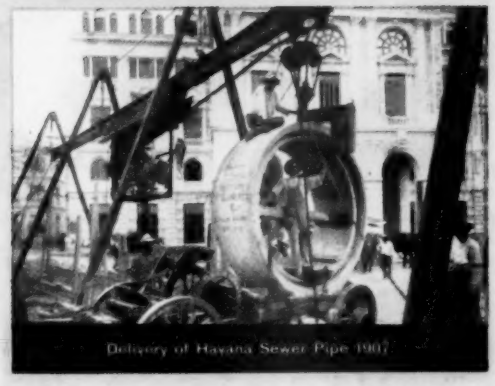
Top right — SACRAMENTO COUNTY, CALIF. (San. Dist. #3) GASLIFTER in 70' dia. digester with fixed concrete cover. Mr. Norman Farnum, Supt. Dewante & Stowell, Sacramento, Cons. Engrs.

WALKER PROCESS EQUIPMENT INC. AURORA, ILLINOIS

a leader in equipment for . . .

SEWAGE TREATMENT • WATER TREATMENT • INDUSTRIAL WASTE TREATMENT

OVER 50 YEARS EXPERIENCE

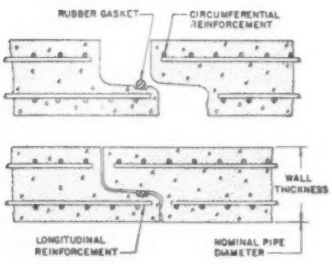


Delivery of Havana Sewer Pipe 1907

Delivery of Roller Suspension Sewer Pipe 1960.

LOCK JOINT

RUBBER and CONCRETE JOINT



SEWER AND CULVERT PIPE PLANTS:

Kenilworth, N. J.
Hartford, Conn.
New Haven, Conn.
Buffalo, N. Y.
Rochester, N. Y.
Edgewater, Fla.
Miami, Fla.
W. Palm Beach, Fla.
Beloit, Wis.
Chicago, Ill.
Rock Island, Ill.
Valley Park, Mo.
N. Kansas City, Kans.
Tulsa, Okla.
Oklahoma City, Okla.
Wichita, Kans.
Denver, Colo.
Cheyenne, Wyo.
Casper, Wyo.
Tucumcari, N. Mex.
Hato Rey, Puerto Rico
Carolina, Puerto Rico
Ponce, Puerta Rico
Caracas, Venezuela

A pioneer in the concrete pipe industry, Lock Joint Pipe Company has devoted over half a century to the development of concrete pipe in this country and to the evaluation and application of outstanding manufacturing techniques from abroad.

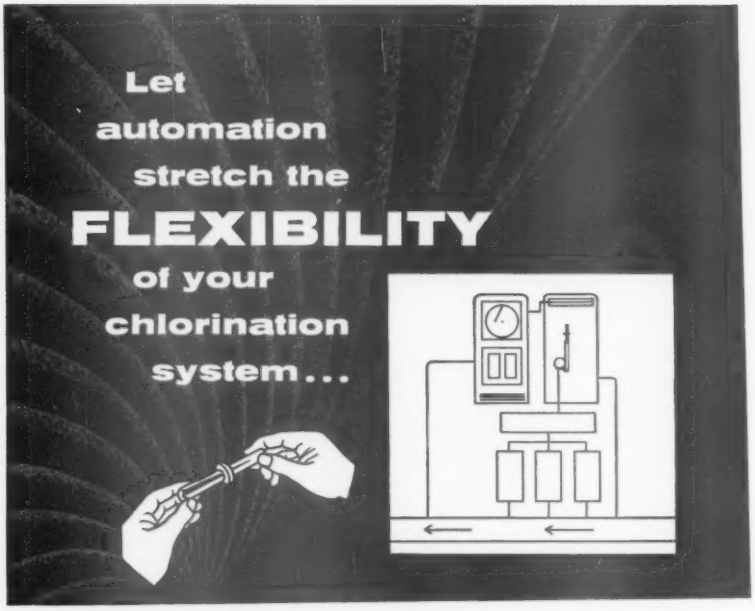
Lock Joint Roller Suspension Sewer and Culvert Pipe points up the value of such research and development. The unique process used in the manufacture of this pipe produces concrete walls of unusual density and abrasion resistance, joint ends of almost machined precision and a joint design giving the ultimate in infiltration protection, and flexibility. Produced in standard 8′ lengths, it ranges in diameter from 12″ to 72″.

Lock Joint also produces machine made and cast pipe ranging in diameter from 6″ to 120″, and even larger if required. All pipe may be designed to comply with A.S.T.M., State Highway or individual specifications.

LOCK JOINT PIPE CO.

East Orange, New Jersey

Pressure • Water • Sewer • REINFORCED CONCRETE PIPE • Culvert • Subaqueous



W&T **COMPOUND-LOOP CONTROL**

Compound-loop Control by Wallace & Tiernan maintains chlorine residuals automatically—provides utmost flexibility in arrangement and process control.

Chlorinator feed rate is adjusted by two signals: one from water flow, the other from continuous, automatic residual analysis. Since feed rate is the product of these signals, Compound-loop Control gives you a range of greater than 100:1. No matter how much flow or demand changes, your system always maintains the selected residual.

Regardless of the size, type, or physical layout of your system, Compound-loop Control adapts readily. Electric, pneumatic, or variable vacuum control signals can be used. And you can install Compound-loop Control as a package or convert to it, component by component, as your system expands.

For more information, write Dept. S-145.84

WALLACE & TIERNAN INCORPORATED
25 MAIN STREET, BELLEVILLE 9, NEW JERSEY

LANCASTER PRESS, INC., LANCASTER, PA.